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Insect Emergence from a small Trout Loch and its bearing on the Food Supply of Fish

By N. C. MORGAN, B.Sc. and Miss A. B. WADDELL, B.Sc.

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Freshwater Fisheries Laboratory, Pitlochry

EDINBURGH: HER MAJESTY'S STATIONERY OFFICE
1961

CONTENTS

	Page
Introduction	3
Site	3
Methods	5
Composition of the Catch	8
Weight of Insects Produced	10
Diurnal Variation in Emergence Rate	12
Seasonal Variation in Numbers	17
Seasonal Variation in Weight	29
Number of Species and Water Temperature	30
Discussion	30
Acknowledgements	36
Summary	36
References	38

The functions of the Scottish Home Department relating to fisheries were transferred on 1st April, 1960 to the Department of Agriculture for Scotland, which will in future be known as the Department of Agriculture and Fisheries for Scotland.

Insect Emergence from a Small Trout Loch and its bearing on the Food Supply of Fish

INTRODUCTION

It is well known that many aquatic insects become most available to fish as a food at the point in their life history when, as the last instar nymphs or pupae, they are making their way to the water surface to emerge as imagines. Borutsky (1939) has shown that, out of an estimated 34·6 million *Chironomus plumosus* L. devoured by perch, gudgeon, crucian carp and roach, 26·0 million were pupae and 8·6 million larvae, and many workers have found chironomid pupae to figure in the food of trout to a much greater extent than the larvae. Therefore to assess the insect fauna of a loch, available as food for trout, it is necessary to have a quantitative measure of the annual cycles of insect emergence in order to know when and in what quantity the various species of insect emerge. The preliminary results of such an investigation are given in this paper. Studies of the seasonal and diurnal variation in emergence rate have been carried out, the number of generations and the fluctuations in the numbers and of the times of emergence of the individual species have been determined and the total emerging fauna has been compared from year to year. Some of the more general results dealing with the total fauna are considered here. An attempt to assess the value to fish of different types of bottom in terms of the productivity at the water surface has been made by comparing the total weight of insects emerging at different sites.

A short summary of the work carried out in 1954 and 1955 has been published (Morgan, 1958).

SITE

The observations described in this paper were made at Loch Dunmore, near Pitlochry, Perthshire during 1955, 1956 and 1957. The loch lies at a height of 350 ft above sea level. It has an area of 4·5 acres and consists of two basins joined by a narrow channel in which the water is only a few inches deep. The emergence of insects was studied in the north basin, which is 2·9 acres in extent. Much of the bottom is at an even depth of 6 ft and consists of mud varying from a few inches to over a foot in depth. Around the shore this is covered by dead leaves. The loch is situated in a mixed wood of coniferous and deciduous trees, the surrounding ground consisting of alluvium. It is skirted for the most part by rhododendron bushes. The loch was originally made by constructing a dam across the neck of a small valley. In dry weather it is fed by seepage but in wet weather a stream also flows into the south basin. Water spills over the dam after periods of rain. There is a rich plant growth (Fig. 1). In summer the pH varies from 7·3-7·7 and the alkalinity from 25-28 mg $CaCO_3$/l., and the corresponding winter ranges are 6·9-7·4 and 20-30 mg $CaCO_3$/l. In 1955 the ice cover lasted from some time prior to 11th January until 30th March; in 1956, from 13th January to 2nd March; and in 1957, from 15th January to 21st January, from 20th to 25th February and from 13th December to the end of the year. The maximum water temperature usually occurs in July. The highest daily maximum temperature at 6 ft depth of water was 20·5°C in 1955, 16·5°C in 1956 and 17·0°C in 1957 and at a depth of 1 ft at the side of the loch 26·7°C in 1955, 19·6°C in 1956 and 21·6°C in 1957.

Insect emergence was studied using emergence traps at six sites (Fig. 1).

Site 1. Situated at the south end of the loch over about 10 inches of water, though the depth of water below the trap decreased during long periods of dry weather to about 4 inches. The bottom

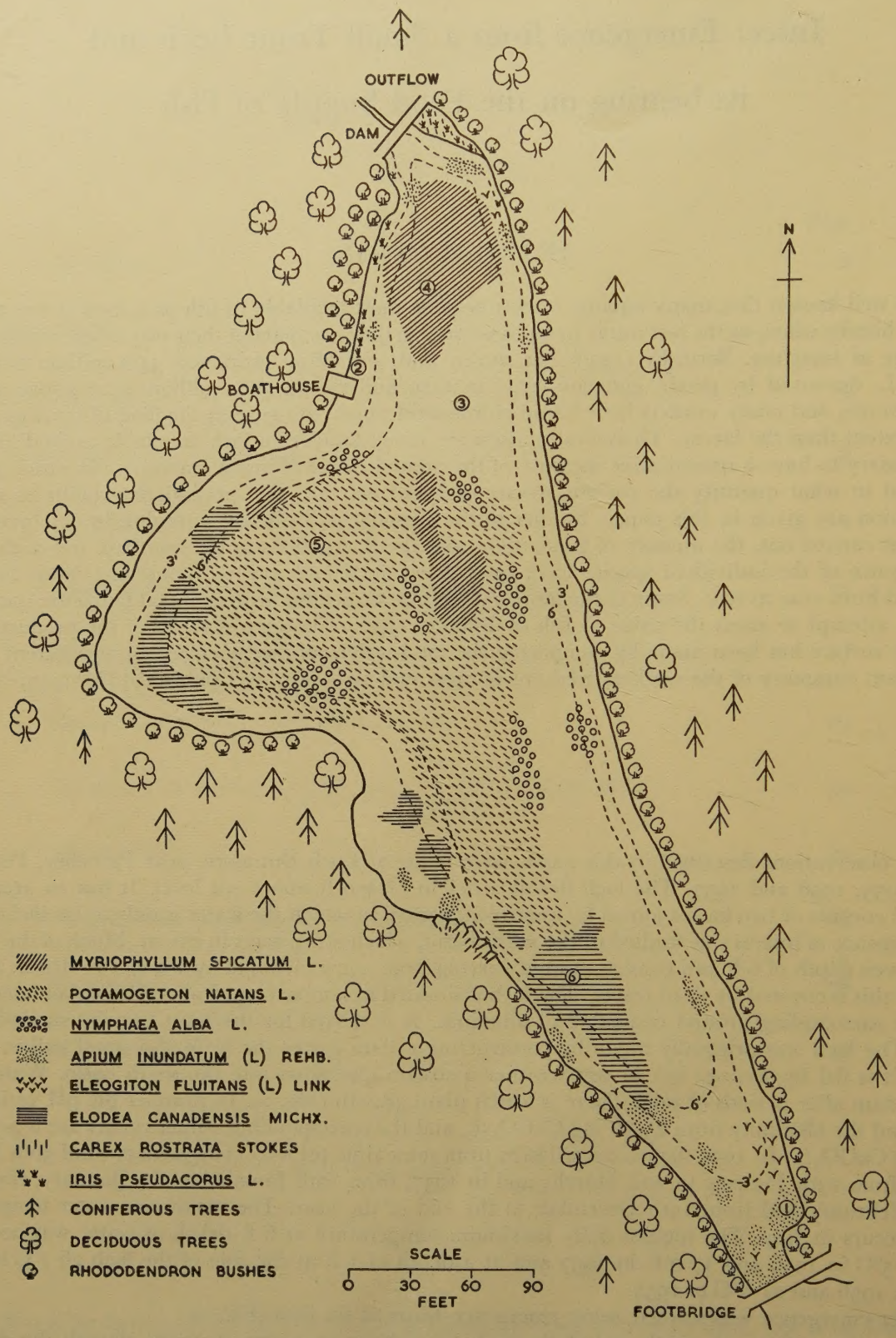

OUTFLOW
DAM
BOATHOUSE
N
3'
6'
-6'
-3'
MYRIOPHYLLUM SPICATUM L.
POTAMOGETON NATANS L.
NYMPHAEA ALBA L.
APIUM INUNDATUM (L) REHB.
ELEOGITON FLUITANS (L) LINK
ELODEA CANADENSIS MICHX.
CAREX ROSTRATA STOKES
IRIS PSEUDACORUS L.
CONIFEROUS TREES
DECIDUOUS TREES
RHODODENDRON BUSHES
SCALE
0 30 60 90
FEET
FOOTBRIDGE

Fig. 1

consisted of mud covered with a dense growth of *Apium inundatum* (L.) Rehb. The area of the trap was 5 sq. ft. This site was studied from 3rd June, 1954 onwards.

Site 2. Situated on the north side of the boathouse where the water depth below the trap ranged from 4 in. to 1 ft. The bottom was mud covered with dead leaves and twigs from the surrounding trees. In 1954 a few leaves of *Menyanthes trifoliata* L. and of *Juncus* spp. were growing below the trap. During May 1955 there was a scattered growth of *Menyanthes trifoliata*, *Apium inundatum* and *Sparganium minimum* L. By August the growth of weeds had increased and covered about half the area under the trap. These were chiefly *Apium inundatum* and *Sparganium minimum* with some *Littorella uniflora* Aschers, *Elodea canadensis* Michx., *Myriophyllum spicatum* L. and *Nymphaea alba* L. On 8th September the trap was moved 9 inches from the bank as the inshore edge of the raft was out of the water due to a drop in water level. A trap of area 7·5 sq. ft was set from 3rd June, 1954 and during 1955.

Site 3. Situated opposite the boathouse over 6 ft of water where the bottom was mud covered with a scattered growth of *Chara delicatula* Agardh. This was probably the most uniform area of bottom of the whole loch. A trap, 5 sq. ft in area, was operated from 14th June, 1954 onwards.

Site 4. Situated over a bed of *Myriophyllum spicatum* growing in 6 ft of water in the north bay. A trap, 4 sq. ft in area, was set from 30th June, 1955 to 13th May, 1957.

Site 5. Situated over a bed of *Potamogeton natans* L. growing in 6 ft of water in the west bay. A trap, 4 sq. ft in area, was operated from 9th August, 1955 onwards.

Site 6. Situated over 6 ft of water where the mud bottom was covered with a dense growth of *Elodea canadensis* extending almost to the water surface. A trap, 5 sq. ft in area, was operated during 1956.

METHODS

The emerging insects were caught in floating emergence traps, which were moored over the particular type of bottom being studied. Adamstone and Harkness (1923), Miller (1941), Scott and Opdyke (1941) and Vallentine (1952) have used floating tent traps consisting of a wood or wire frame covered with cotton or muslin in order to catch adult insects. Macan (1949) employed floating cages made of a wooden frame covered with celluloid and mosquito netting.

It was not possible to use funnel traps, of the type used by Borutsky (1939) and others, at Loch Dunmore as some sites were situated in very shallow water and others over dense weed. Since the loch was protected from high winds by the surrounding trees floating cages were found to be suitable.

The type of floating emergence trap used at Loch Dunmore was similar to that used by Macan (1949) and is shown in Fig. 2. The trap itself consisted of a box-like frame 1 ft high made of 1 in. × 1 in. wood which was covered with 'Perspex' sheet (1/16 in. thick) on the top and 'Tygan' screen cloth (24 meshes to the inch) on the sides. The bottom of the trap was open to the water surface. The trap was seated within a wooden framework supported by buoys so that the bottom of the trap was just below the water surface. In the original traps the tops were covered with celluloid but this did not stand up to the weather conditions, particularly hot sun, as it became opaque and tended to crack. 'Perspex' was found to be very durable and after three years' use showed no signs of wear. The transparency of the 'Perspex' is important in reducing the shading effect of the traps. The 'Perspex' and 'Tygan' screen cloth were held in position by wooden laths (1 in. × $\frac{1}{4}$ in.) pinned to the frame of the trap. It is important that the lath should overlap the frame slightly in order to hold the screen cloth tightly against the frame, otherwise the smaller insects crawl into the gaps between the screen cloth and the frame. Collection of the insects was facilitated by rounding the inner angles of the frame with putty or plastic wood and by painting the framework white. The traps were washed frequently during use.

The rafts were held in position by ropes attached to the four corners and leading to bricks on the bottom of the loch. The traps were set in position after the ice had left the loch, usually during March, and were left out until the end of November, a month after all emergence had ceased. Traps set over holes made in the ice during March 1955 caught nothing.

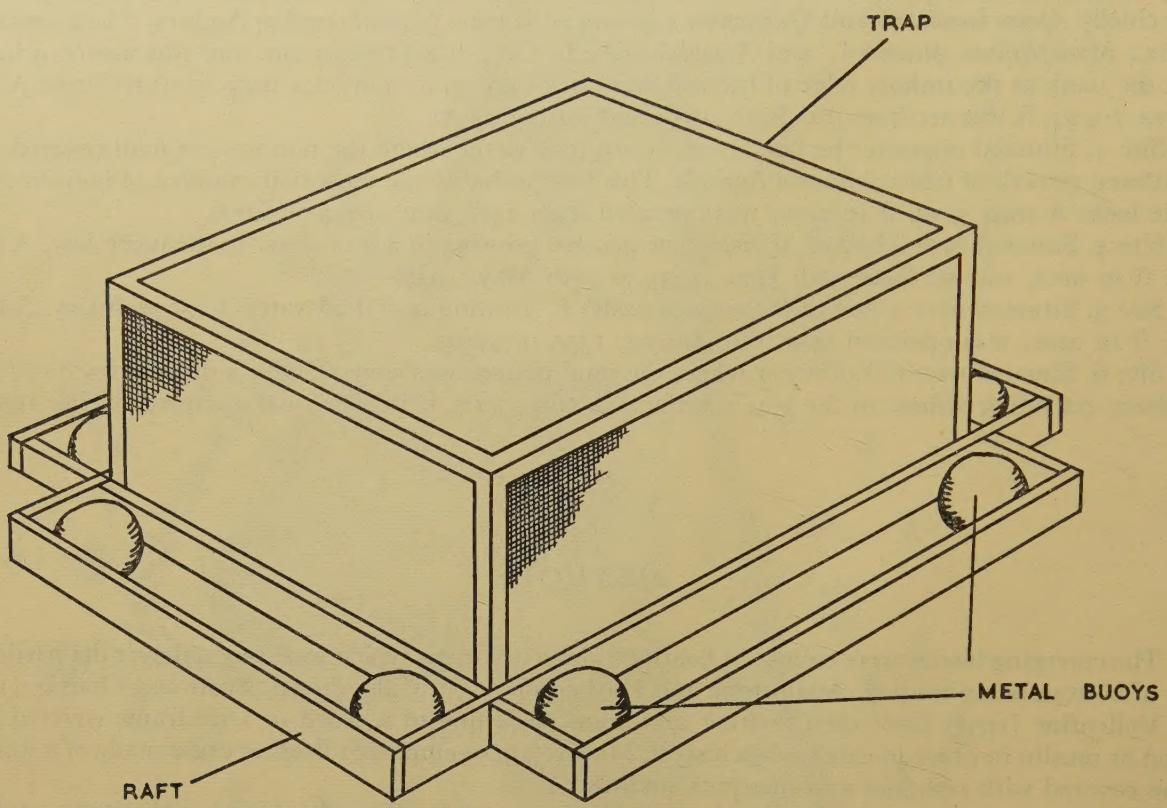


Fig. 2 Floating emergence trap.

To empty the traps, they were slid on to an aluminium sheet fitted to a wooden frame, and carried to the boathouse. There they were tilted with the top towards the window and the open side towards the relatively dark interior of the boathouse, and the insects removed using an entomological aspirator. The imagines were strongly attracted towards the light and very few escaped during this process. When observations were being carried out during the night the traps were tilted towards a 1,000 candle power Tilley lamp.

The insects were kept alive for 24 hours in jars in the laboratory in order to allow the colours to develop fully. They were then killed using ethyl acetate and preserved dry in small glass tubes. This was most important in the case of the Chironomidae since the keys of Edwards (1929) and Coe (1950) were mainly used in the identification and these are based upon dry material. During 1957 the catches were weighed, on a balance accurate to 0·1 mg, immediately after killing. At the time of lifting the traps any insects which had fallen on the water surface were removed together with any pupal exuviae. These were preserved in 70% alcohol.

The catches were identified using the following keys: Odonata (Fraser, 1949); Ephemeroptera (Kimmins, 1954); Trichoptera (Mosely, 1939) using the revised nomenclature of Kimmins (1949) for the Leptoceridae; Dixinae and Chaoborinae (Freeman, 1950); Chironomidae using the keys mentioned in the previous paragraph supplemented by Wülker (1956) for the identification of the *Psectrocladius* spp. and Goetghebuer (1936-50) for those species new to the British fauna. The nomenclature for the Chironomidae is based on that used by Goetghebuer (loc. cit.) except that *Chironomus* Meig. is used instead of *Tendipes* Meig. and (following Freeman, 1957) the sub-genus *Dicrotendipes* Kieff. is used instead of the sub-genus *Limnochironomus* Kieff. Except for the Ceratopogonidae all groups were identified to species wherever possible. By 1957 the fauna was sufficiently well known for almost complete identification to species of each collection.

The traps were lifted daily at 1000 hrs except on Sundays, and the daily catch for the weekend period was taken as the Monday morning catch divided into two. During 1955 the traps were removed occasionally for cleaning and repairs. The catches for the periods when the traps were raised for several days were calculated by proportion from the results of the daily catches before and after. In 1956 and 1957 duplicate traps were available which were substituted when the traps in use required repair.

Traps of different sizes operated at the same site gave a similar pattern for seasonal and diurnal variation in emergence rate.

There was no significant difference between the total number of insects caught in 24 hrs during two-hourly collections and the number caught when the traps were emptied once a day on the days before and after the two-hourly collections. Sprules (1947) found that the daily catch when the traps were emptied every two hours was more than double that when the traps were emptied once in 24 hrs. This phenomenon is probably associated with stream conditions where insects landing on the water surface may be swept away by the current.

It was found that insects with a wing length of less than 1·5 mm were able to pass through the 'Tygan' screen cloth. The length of the sides of the square aperture between the strands of the plastic screen cloth was 0·28 in. (0·7 mm). None of a batch of 40 *Tanytarsus glabrescens* Edw. (?), wing length 1·7 mm, which were introduced into a small cage of screen cloth in the laboratory escaped during a period of 24 hrs. The species with a wing length of less than 1·5 mm were *Corynoneura scutellata* Winnertz, *Limnophyes hydrophilus* Goetgh. and the second generation of *Smittia cheethami* Edw. and records of these species have been omitted.

Various tests on the efficiency of the emergence traps were carried out and the results of these will be published separately.

Continuous records of air and water temperature at a depth of 1 ft at site 2 were taken on a Negretti and Zambra 'Mersteel' Recorder. The temperature at a depth of 6 ft was recorded from daily readings of a maximum and minimum thermometer suspended at site 3. As the thermometer indices were reset at the water surface each day the minimum reading on return to the surface was taken as the water temperature at the bottom.

The times recorded in this paper are British Summer Time (one hour ahead of Greenwich Mean Time).

COMPOSITION OF THE CATCH

The number of insects which emerged per square yard at different sites in a year is given in Table 1. Where results are available for several years these are given. The catches consisted mainly of Chironomidae, Ephemeroptera and Trichoptera. In the table the Chironomidae have been separated into Tanypodinae, Orthocladiinae and Chironominae. A few which were taken from the water surface and were unidentifiable further than to Chironomidae are grouped as 'Unidentified Chironomidae'. Odonata, Tipulidae, Culicidae and Ceratopogonidae which emerged in smaller numbers have been grouped under the heading 'Other Insects'.

The total number of insects caught at the shallow water sites 1 and 2 was much less than at the deeper water sites 3, 4 and 5. At site 1 the number was about half that at the deeper sites and site 2 produced less than one third of the number at site 3, where the biggest catches were taken. Judd (1953) collecting from Dundas Marsh, where the depth of water was 28-58 in. dropping by 2 ft by the autumn, caught an average of 3,681 insects per sq. yd between March and October. This is somewhat lower than the catch at the two shallow water sites at Loch Dunmore. Judd found that the cages over deeper water produced the most insects. Ide (1940), working on a stream, caught 15,077 imagines/sq. yd from fast flowing water from 4th May to 15th September and from a similar area 26,803 insects from 25th May-18th September. At the latter site half the insects were Simuliidae. From a slower flowing part of the stream with silting and emergent vegetation he caught 9,065/sq. yd. The size of the catch from the fast flowing areas was similar to that from the deeper water sites at Loch Dunmore and from the slow flowing part of the stream was intermediate between the numbers taken from shallow and deeper water at Loch Dunmore. Sprules (1947), also working on a stream, caught 5,393-7,175 insects/sq. yd between 1st June and 31st August at different sites where the bottom consisted of a few rocks embedded in gravel and 31,505/sq. yd where the bottom was formed of many rocks built up in layers.

At all sites at Loch Dunmore the Chironomidae were more numerous than the other groups put together. At the deeper water sites, where their numbers were greater, they formed a greater proportion of the total emerging fauna than in shallow water. This proportion was considerably less at site 1 and closer to that of the deeper water sites at site 2. The average number of Chironomidae and their percentage of the total catch were as follows: site 1, 4,885/sq. yd (68·8%); site 2, 4,375/sq. yd (87·0%); site 3, 16,047/sq. yd (92·2%); site 4, 14,298/sq. yd (94·4%); site 5, 12,010/sq. yd (92·0%). The proportion of Tanypodinae caught at the shallow water sites was much higher than that caught from the deeper water sites. The numbers of Tanypodinae were of the same order from the shallow water sites and from *Myriophyllum spicatum* at site 4 and were lowest from site 3 where the only vegetation was a sparse growth of *Chara delicatula*. The Orthocladiinae were most numerous from *Myriophyllum spicatum* at site 4 and *Potamogeton natans* at site 5. In 1956, 10,700 Orthocladiinae, forming 66·8% of the total emerging fauna were caught per sq. yd at site 5, of which 9,837 were *Psectrocladius* spp. Relatively few Orthocladiinae were taken from the shallow water and from site 3. The Chironominae were found in the greatest numbers at site 3 where the average catch over three years was 14,246/sq. yd comprising 81·9% of the total emerging insects. They were chiefly *Tanytarsus* spp. which, in 1956, numbered 12,227 out of a total of 17,698 Chironominae per sq. yd. At the other deep water sites the total Chironominae was less than half the average at site 3 and in shallow water never more than 2,500/sq. yd.

The Ephemeroptera were most numerous at the shallow and weedy site 1 where *Cloëon simile* Eaton, *Leptophlobia vespertina* L. and *Caenis horaria* L. were the most common species. This group comprised 19·6% of the total catch at this site. At site 3 the Ephemeroptera averaged 1,069/sq. yd forming only 6·1% of the total emerging insects, and were nearly all *C. horaria*. At the other sites the Ephemeroptera were less numerous.

The Trichoptera were caught most frequently at the weedy sites 1, 4 and 5 and in smaller numbers at the other two sites where there was less vegetation. *Athripsodes aterrimus* Steph., *Triaenodes bicolor* Curt., *Mystacides azurea* L., and *Limnephilus marmoratus* Curt. were common at the shallow water sites. From deeper water *Oxyethira costalis* Curt. and *Cyrnus flavidus* McLach. were most common at all sites, while *Limnephilus marmoratus* was common at the weedy sites but not from the mud bottom at site 3. The pre-

TABLE 1

The Composition of the Annual Catch expressed as Number/Sq. Yd

Site	Year	Total Insects	Ephemeroptera		Trichoptera		Tanypodinae		Orthocladiinae		Chironominae		Unidentified Chironomidae		Other Insects	
			No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1	1955	7040	1269	18·0	369	5·2	1532	21·8	952	13·5	2448	34·8	65	0·9	405	5·8
1	1956	7711	2203	28·6	256	3·3	2282	29·6	952	12·3	1692	21·9	157	2·0	169	2·2
1	1957	6580	709	10·8	470	7·1	2414	36·7	691	10·5	1418	21·6	52	0·8	826	12·6
Average of 1		7110	1393	19·6	365	5·1	2076	29·2	865	12·2	1853	26·1	91	1·3	467	6·6
2	1955	4999	353	7·1	174	3·5	1804	36·1	205	4·1	2320	46·4	28	0·4	115	2·3
3	1955	16934	1190	7·0	178	1·1	454	2·9	290	1·7	14650	86·5	65	0·4	108	0·6
3	1956	22502	1705	7·6	171	0·8	1580	7·0	956	4·2	17698	78·7	367	1·6	25	0·1
3	1957	12758	311	2·4	108	0·8	943	7·4	702	5·5	10390	81·4	47	0·4	257	2·0
Average of 3		17398	1069	6·1	152	0·9	992	5·7	649	3·7	14246	81·9	160	0·9	130	0·7
4	1956	15172	328	2·2	398	2·6	2498	16·5	5090	33·6	6610	43·6	100	0·7	148	1·0
5	1956	16010	433	2·7	333	2·1	1290	8·1	10700	66·8	2820	17·6	25	0·2	410	2·6
5	1957	10090	433	4·3	245	2·4	1440	14·3	2988	29·6	4728	46·9	28	0·3	228	2·3
Average of 5		13050	433	3·3	289	2·2	1365	10·5	6844	52·4	3774	28·9	27	0·2	318	2·4

ponderance of *Athripsodes aterrimus* emerging in shallow water was due to their habit of migrating inshore to pupate (Morgan, 1956).

The 'Other Insects' were most important at site 1 where they averaged 6·6% of the emerging fauna. At all sites the 'Other Insects' were mainly Ceratopogonidae or the culicid *Chaoborus flavicans* Meig. The Ceratopogonidae were most numerous at site 1 (average 295/sq. yd) and at site 3 (average 109/sq. yd) and *Chaoborus flavicans* was closely associated with the weedy sites 1, 4 and 5 where an annual average of 105, 108 and 181/sq. yd emerged. *C. flavicans* was less common where there was less weed, for example, at site 2 only 34/sq. yd were caught and at site 3 only 20/sq. yd.

Judd (1953) found that his catches consisted of 9·9% Ephemeroptera, 0·5% Trichoptera, 80·6% Chironomidae and 9·0% other insects. These are similar proportions to the collections taken from Loch Dunmore. In a stream Ide (1940) caught 30·3% Ephemeroptera, 1·7% Plecoptera, 6·6% Trichoptera, 30·9% Chironomidae, 28·2% Simuliidae and 2·2% other insects where the water was fast flowing over a stony bottom and 4·4% Ephemeroptera, 1·7% Trichoptera, 90·3% Chironomidae, 2·3% Simuliidae and 1·3% other insects where the stream was slower flowing with silting and emergent vegetation. These percentages are calculated from the numbers given by Ide. The composition of the fauna in the slow flowing part of the stream approximated closely to the composition of the emerging fauna at Loch Dunmore.

The considerable difference in the numbers of some groups from year to year at the same site is shown clearly in Table 1 (e.g. the numbers of Ephemeroptera emerging at sites 1 and 3 in 1956 and 1957). This change was due to a fall in the numbers of *Cloëon simile* and *Caenis horaria* caught at site 1 and the *C. horaria* at site 3. Similar changes in the number of Chironomidae emerging from year to year occurred. The total number of Trichoptera remained more constant at any one site although the same was not true of the individual species. Ceratopogonidae were caught in small numbers at all sites in 1956. At site 1 there were 76 in 1956 and 592 in 1957 and at site 3 there were 7 in 1956 and 218 in 1957.

The total number of insects caught at all sites was higher in 1956 than in the other years. Most of the commoner species were more plentiful although some showed little change in numbers and some were less common in 1956. July and August 1955 were exceptionally warm and sunny months. These exceptional conditions may have caused an increased production of algae resulting in a higher survival than usual of the larvae hatching from eggs laid in the summer of 1955. Lundbeck (1926) found that 96% of the larvae of *Tanypus* perished in the period of embryonic development and in an initial larval stage and Borutsky (1939) estimated that 92% of the *Chironomus plumosus* of Lake Beloie also perished in these stages. Thus a reduction of about 5-10% in the mortality at this time, due to increased food supply, could well result in double the production of adults the following spring provided the food supply lasted long enough.

WEIGHT OF INSECTS PRODUCED

A comparison of the weight of adult insects leaving one square yard of the water surface in a year at different sites is given in Table 2. The lowest weight produced was at the deeper site 3, with little plant growth, and was less than one third of the weight of insects emerging at the shallow and weedy site 1 and about two fifths of that emerging at the deeper and weedy site 5. The shallow site with a dense growth of *Apium inundatum* was the most productive, though production may have been increased to some extent by some species migrating inshore prior to emergence. The importance of the presence of macrophytes is well illustrated by site 4 where up to the 9th May the weight of insects emerging from *Myriophyllum spicatum* was greater than that emerging in the whole year from site 3. The importance of knowing the weight of insects produced is emphasised by the fact that the greatest *number* of insects per annum were caught at site 3 whereas the traps over shallow water caught the least.

It is also necessary to know the identity of the fauna when assessing the production of fish food from different areas. The weights of a few of the species caught are shown in Table 3. For the larger insects the weights given are the average of at least ten newly emerged individuals and for the smaller insects the average of a much larger number than ten. As well as the weights, the equivalent number of

TABLE 2

Total Weight of Insects emerging from Loch Dunmore, 1957

	W (mg/sq. yd)	$\frac{\text{W at site}}{\text{W at site 3}}$
Site 1	17,451	3·4
Site 3	5,068	1·0
Site 5	13,284	2·6
Site 4*	7,262	1·4

*For the period up to 9th May

male *Tanytarsus glabrescens* Edw. (?), which is the smallest insect which the traps retain, is shown for each species. From this it can be seen that the 12,227 *T. glabrescens* (?) emerging per square yard at site 3 are only equivalent to about 33 *Limnephilus marmoratus,* which is less than the number of the latter which emerged at the weedy site 5 in a year.

TABLE 3

The Individual Weights of some of the Commoner Species of Insects emerging from Loch Dunmore

Species	Weight (mg)		Equivalent No. of *Tanytarsus glabrescens* (?) males	
	Male	Female	Males	Females
Enallagma cyathigerum	33·2	35·8	221	239
Cloëon simile	7·7	10·0	51	67
Caenis horaria	0·9	2·1	6	13
Athripsodes aterrimus	3·7	5·0	25	33
Limnephilus marmoratus	54·8	57·9	365	387
Oxyethira costalis	0·3	0·5	2	3·3
Ablabesmyia cingulata	0·3	0·5	2	3·3
Procladius choreus	1·6	2·1	11	15
Psilotanypus lugens	0·9	1·1	6	7·3
Chironomus tentans	7·9	17·6	53	117
Chironomus anthracinus	3·2	5·9	21	40
Microtendipes chloris var. lugubris	2·4	4·1	16	27
Tanytarsus samboni	0·3	0·3	2	2
Tanytarsus glabrescens (?)	0·15	0·2	1	1·3

As well as big differences in weight between different groups there is wide fluctuation between species within the same group. Thus the large caddis *Limnephilus marmoratus* weighs over a hundred times more than the small *Oxyethira costalis*. *Chironomus tentans* Fabr., which is the largest chironomid found at Loch Dunmore, weighs about as much as the mayfly *Cloëon simile*. The medium sized chironomids such as *Procladius choreus* Meig. and *Microtendipes chloris* var. *lugubris* Kieff. weigh more than the small mayfly *Caenis horaria* and the small caddis *Oxyethira costalis* both of which are common species. The largest emerging insects at Loch Dunmore were the Phryganidae, Limnephilidae and the Zygoptera, for example, *Limnephilus marmoratus* and *Enallagma cyathigerum* Charp. (Table 3). These insects are of far greater weight than the other common species and could therefore be of considerable importance as fish food. The weights of the other species indicate the large number of the smaller Ephemeroptera, Trichoptera and Chironomidae which would have to be caught by fish to consume an equivalent weight of food. On the other hand the numbers of the large species present is small compared with the numbers of the small insect species.

The individuals of those species with more than one generation within a year were lighter in the later generation. Thus in May the weight of *Cloëon simile* averaged 10·0 mg (males) and 12·9 mg (females), but in August, the average weight of the males was 6·1 mg and that of the females 7·3 mg. With the

exception of *Tanytarsus samboni* Edw. the average weights of newly emerged females, which had not laid their eggs, was greater than that of males.

DIURNAL VARIATION IN EMERGENCE RATE

Diurnal variation in the rate of emergence of the individual species will be described in a separate paper (in draft) and related to diurnal changes in the physical conditions. A description of diurnal variation in the emergence rate of the total fauna is given in this paper since it is this which affects the amount of emerging insects available to fish at any time within a twenty four hour period.

The emergence in late March and early April from *Myriophyllum spicatum* growing in 6 ft of water is shown in Fig. 3a. Emergence rate was highest in the middle of the day and there was no emergence at night. With the exception of four chironomids belonging to other species the emergence was composed entirely of *Chironomus anthracinus* Zett. At the other sites emergence rate was so low at this time of year that diurnal studies were not possible.

The emergence rate at sites 1, 2 and 3 in May is shown in Fig. 3b-d. At site 1 the maximum emergence occurred in the middle of the day, 1200-1400 hrs, due to the emergence of *Cloëon simile*. At site 2, where there was little vegetation, very few Ephemeroptera emerged and the slight rise in total numbers from 1000-1800 hrs was due to the emergence of the chironomid *Psilotanypus lugens* Kieff. There was no evening increase at this site. The diurnal pattern at site 3 followed that of *Tanytarsus samboni* which caused a sudden evening rise in the total from 2000-2200 hrs.

In June, the diurnal pattern at the shallow and weedy site 1 showed pronounced midday and midnight peaks (Fig. 3e). The midday peak was made up largely of *Leptophlebia vespertina, Cloëon simile* and *Athripsodes aterrimus,* and that at midnight by several species of chironomids. At site 2 (Fig. 3f) the collections were one hour later than those at sites 1 and 3 due to the time taken to remove the large collections from traps at site 3. Again the numbers emerging in the middle of the day were much lower than at the other shallow water site. The maximum emergence occurred between 2100 and 0100 hrs when a considerable number of *Tanytarsus glabrescens* (?) were caught at the beginning of the month and *Chironomus* (*Cryptochironomus*) *edwardsi* Krusem. were caught at the end of the month. The emergence maximum at site 3 (Fig. 3g) from 2200-2400 hrs was dominated by the large numbers of *Tanytarsus glabrescens* (?) which emerged at the beginning of the month. *Lauterborniella orophilus* Edw. emerged in considerable numbers from 1000-2000 hrs so that there was a high emergence rate during the afternoon at this site. The insects other than chironomids caught between 2000 and 2400 hrs were nearly all *Caenis horaria*. If the results from the beginning and end of the month had been graphed separately the 2200-2400 hr maximum at the end of the month would be far less pronounced due to the smaller numbers of *Tanytarsus glabrescens* (?) emerging at that time.

The diurnal variation in July is shown in Fig. 4a-d. At site 1 the maximum occurred from 2200-2400 hrs when several species of Chironomidae and Trichoptera emerged together in small numbers, rather than a high proportion of the catch consisting of one species. The slight increase in the middle of the day was caused by *Leptophlebia vespertina* and *Cloëon simile*. At sites 2, 3 and 4, where the diurnal pattern was similar, the chironomid maximum occurred from 2000-2400 hrs when again the total was built up of small numbers of a variety of species. The highest emergence rate occurred between 2000 and 2200 hrs when the maximum emergence of *Caenis horaria* took place.

A variation in the size or a slight shift in the time of the seasonal maxima can produce a different diurnal pattern of emergence in the corresponding week from year to year. This is illustrated by comparing the July results from site 3 in 1954 and 1955 (Figs. 4f and d). In 1954 an emergence of *Tanytarsus* spp. between 2200 and 2400 hrs caused the diurnal maximum of the total to occur within this period, whereas in the absence of this emergence in 1955 the maximum of the total coincided with the maximum of *Caenis horaria* two hours earlier.

The diurnal variation in August is shown in Fig. 4e and g-j. Apart from site 1 the daily pattern at the different sites is very similar. At site 1 the maximum chironomid emergence occurred between 2000 and 0400 hrs rising slightly at either end of this period. It consisted of several species the maxima of

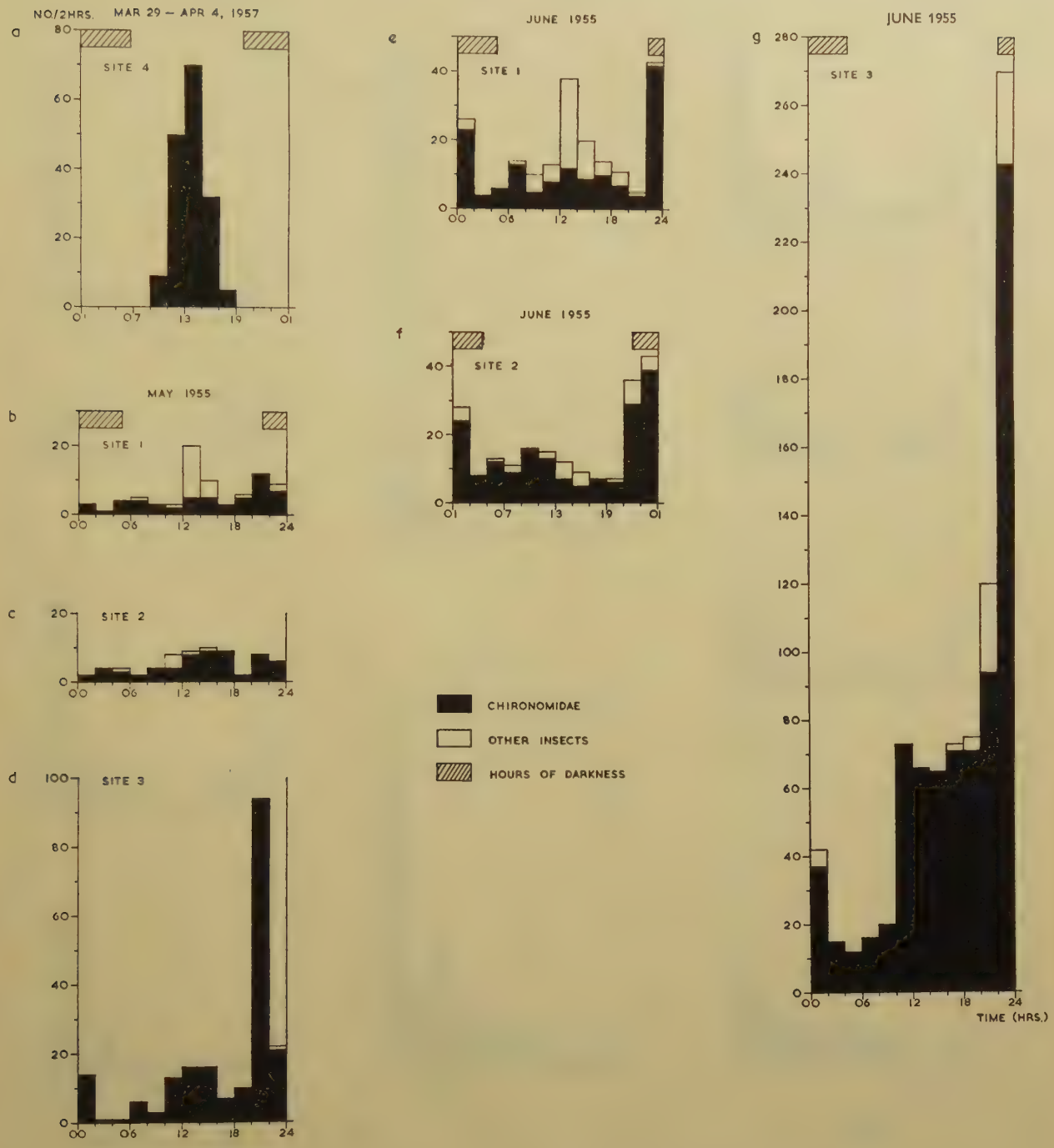


Fig. 3 Diurnal fluctuation in the total number of insects emerging.

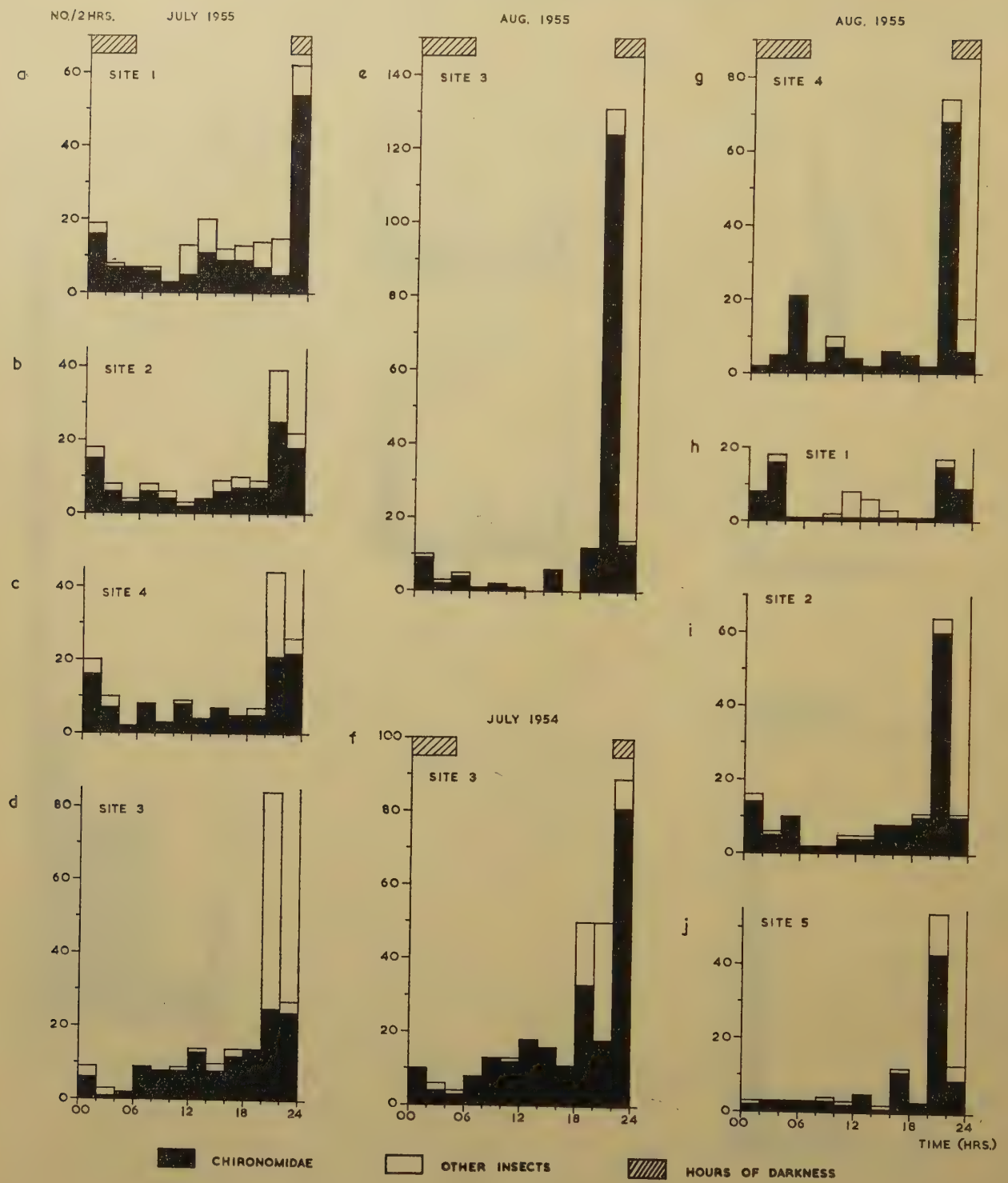


Fig. 4 Diurnal fluctuation in the total number of insects emerging.

which coincided during this period. The rise in emergence rate in the middle of the day is caused by the emergence of *Cloëon simile* between 1000 and 1400 hrs. In spite of the overall similarity of emergence pattern at the other sites the pronounced maximum between 2000 and 2200 hrs was made up of different species at each site. At site 4 the secondary rise in emergence rate between 0400 and 0600 hrs was caused by the secondary emergence peak of *Psectrocladius psilopterus* Kieff. This species was atypical in that it showed a bimodal emergence rhythm, the maximum emergence rate occurring between 2000 and 2200 hrs with a secondary rise in emergence rate between 0400 and 0600 hrs.

During September the emergence rate was low and the catches during two-hourly collections were small. At the shallow water sites 1 and 2 there was a slight rise in emergence rate in the middle of the day when *Cloëon simile* emerged and at site 3 a slight increase in the emergence rate of chironomids in the two hours following dusk.

The diurnal pattern of emergence can show a considerable variation from site to site at the same time of year, as in May and June. When the diurnal pattern is similar at different sites the specific composition may be very different, as in August. Overall the maximum emergence rate occurs in the late evening from June to August. This is caused by the emergence of certain common chironomid species in the period following sunset and by the evening emergence of *Caenis horaria*. At the shallow site 1 with a dense growth of *Apium inundatum* there was a tendency in all months towards a secondary peak around midday, when *Cloëon simile, Leptophlebia vespertina* and *Athripsodes aterrimus* emerged. There was no evening rise in emergence rate at the shallow water sites in May. During late March and early April at site 4 there was a large emergence during the day (between 0800 and 1800 hrs) and none at night. In each month at all sites, except site 4 in August, the period from about 0400-0800 hrs was a time when there was very little emergence. This differs from the findings of other workers. Scott and Opdyke (1941) found that the period of minimum emergence in August was from 0600-1600 hrs following the second highest emergence period 0400-0600 hrs. Miller (1941) based on two days' observations, found that in July very few insects emerged between 0700 and 0400 hrs, whereas Sprules (1947) found the minimum emergence was at 1500-1800 hrs which was the time of maximum water temperature. At Loch Dunmore the minimum emergence period was about dawn when the water temperature was low and the light intensity increasing rapidly. The late evening maximum of chironomid emergence from May to August was related to the maximum emergence of some of the common chironomid species occurring just after sunset, as a response to the change from light to darkness. This agrees with the findings of Sprules (1947) working on a stream and Palmén (1955) for the emergence of nine chironomid species from the Baltic. Thus at Loch Dunmore the maximum emergence of the Chironomidae occurred within the period 2000-2200 hrs in May, 2200-2400 hrs in June and July and 2000-2200 hrs in August in relation to the time of sunset. On the other hand Miller (1941) found that the emergence rate of Chironomidae from 1 m depth was greatest between 0400 and 0700 hrs when it was at a minimum at Loch Dunmore. Scott and Opdyke (1941) found that the maximum emergence of Diptera occurred between 1800 and 2400 hrs with a smaller increase in emergence rate from 0400-0600 hrs. This is similar to the results obtained at Loch Dunmore for site 4 in August when *Psectrocladius psilopterus* was emerging.

To obtain a better measure of the value of the peak emergence periods in terms of available fish food it is necessary to know the mass of material leaving the water surface per unit area since the variation in size both within and between different groups of insects is large as has been shown in Table 3. The diurnal variation in the total weight of insects emerging is shown in Fig. 5. The deeper water sites are represented by site 3, except in March and April when site 4 was used, and the shallow water by site 1. The histograms show the total estimated weight of insects (in mg) caught from an area of 5 sq. ft during the same two-hourly period in four days. The weights used for estimation were obtained by weighing the individual species during 1957.

Comparing Fig. 5 with Figs. 3 and 4 for May to August the weight of organisms emerging from site 1 during the maximum period of emergence is greater than from site 3 although in all cases the numbers of organisms at site 3 is greater. In each month a large weight of organisms emerged from site 1 in the middle of the day due to the emergence of *Leptophlebia vespertina, Cloëon simile* and *Athripsodes atterimus* at this time. In July the maximum weight of insects emerged from site 1 between 2200 and 2400 hrs. Out of 62 insects emerging during this period 54 were chironomids and of the eight others two were *Limnephilus marmoratus* which weighed 61% of the total catch, illustrating the importance of

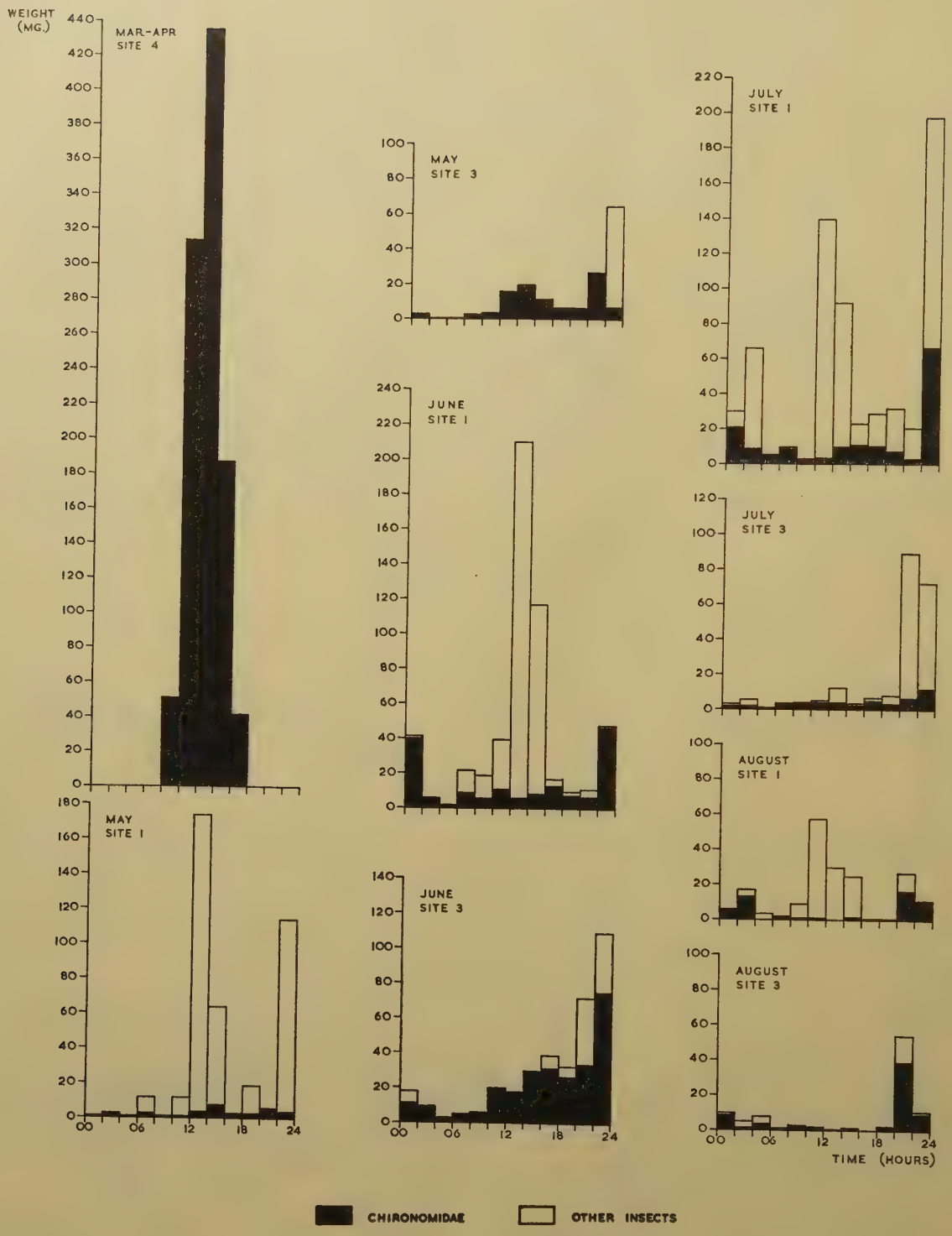


Fig. 5 Diurnal fluctuation in the total weight of insects emerging.

the larger caddis. Table 3 shows that one *L. marmoratus* is equivalent to 365-387 *Tanytarsus glabrescens* (?). In May although 94 chironomids, chiefly *Tanytarsus samboni*, emerged at site 3 between 2000 and 2200 hrs, compared with 20 insects at site 1 from 1200-1400 hrs, the corresponding weights were 27 mg and 174 mg. The only time at which the weight of emerging chironomids was high was at the end of March and beginning of April when *Chironomus anthracinus* emerged over the midday period. This insect was equivalent to 21-40 *Tanytarsus glabrescens* (?). The total weight produced per unit area in the period 1000-1400 hrs at site 4 at the end of March and beginning of April was greater than at any other site over any two hour period at any other time of year. The relative importance of the evening emergence of *Caenis horaria* to the chironomid emergence at site 3 is illustrated by the July weights when all the insects other than chironomids emerging between 2000 and 2200 hrs were this species.

SEASONAL VARIATION IN NUMBERS

In this paper only the seasonal emergence of the total fauna will be described as it is intended to publish the data on the emergence periods of individual species at a later date.

The weekly totals over the whole emergence period have been used in the figures for seasonal variation but, in order to show the degree of variation in numbers emerging from day to day the daily total for site 3 over the period of maximum emergence rate in 1957 has been plotted (Fig. 6). Miller (1941, Fig. 4) and Judd (1953, Fig. 10) found erratic and considerable fluctuations, sometimes of the order of two times, in numbers from day to day. The fluctuation in total numbers at Loch Dunmore was far less erratic from day to day, the numbers increasing more gradually to the seasonal maxima and decreasing steadily from those maxima.

The seasonal emergence at site 1 over three years is shown in Fig. 7. The emergence period extended from April to September. In 1955 the first insect emerged at this site on 12th April when the average water temperature in shallow water was 9·9°C. In 1956 the first insect captured was on 9th April when the water temperature was 7·6°C and in 1957 on 28th March when the water temperature was 7·3°C. In 1957 the mean weekly water temperature had been above 7°C for nearly three weeks prior to the first emergence and, comparing the temperature curves for the three years (Fig. 8), it is reasonable to assume that the commencement of emergence in 1957 nearly two weeks ahead of the other years was related to the higher water temperatures in March of that year. In 1955 when the temperature at the beginning of emergence was higher than in the other two years the temperature had risen very rapidly from a low temperature in February.

In each year the maximum emergence rate occurred in the second half of June and the total catch for June, expressed as a percentage of the total annual catch was 35·1% in 1955, 33·7% in 1956 and 41·7% in 1957. Maximum water temperature was reached at the end of July in 1955, in mid-July in 1956 and in mid-June in 1957, so that maximum water temperature does not always coincide with maximum numbers emerging.

There were four peaks in chironomid emergence in 1955 and 1956; in April, May, June and July. The three later peaks occurred at the same time each year though the April peak was slightly earlier in 1956 than 1955. The magnitudes of the peaks varied considerably between years, the May and June peaks being of similar size in 1956 whereas in 1955 the May peak was less than one third of the June maximum. In 1955 the June and July emergences of Chironomidae reached a higher rate at their maxima than in the other two years. In 1957 separate chironomid peaks were not discernible, the weekly totals rising steadily to the late June maximum and falling until the beginning of August when there was a slight rise in chironomid emergence rate.

There was considerable variation in the composition of the catches of chironomids at the time of maximum emergence from year to year due to big variations in the numbers of each species and slight differences in the time of maximum emergence of individual species.

There was also a big variation, both in numbers and time of emergence, of the species belonging to other groups of insects from year to year. As these other insects were more numerous at site 1 than at

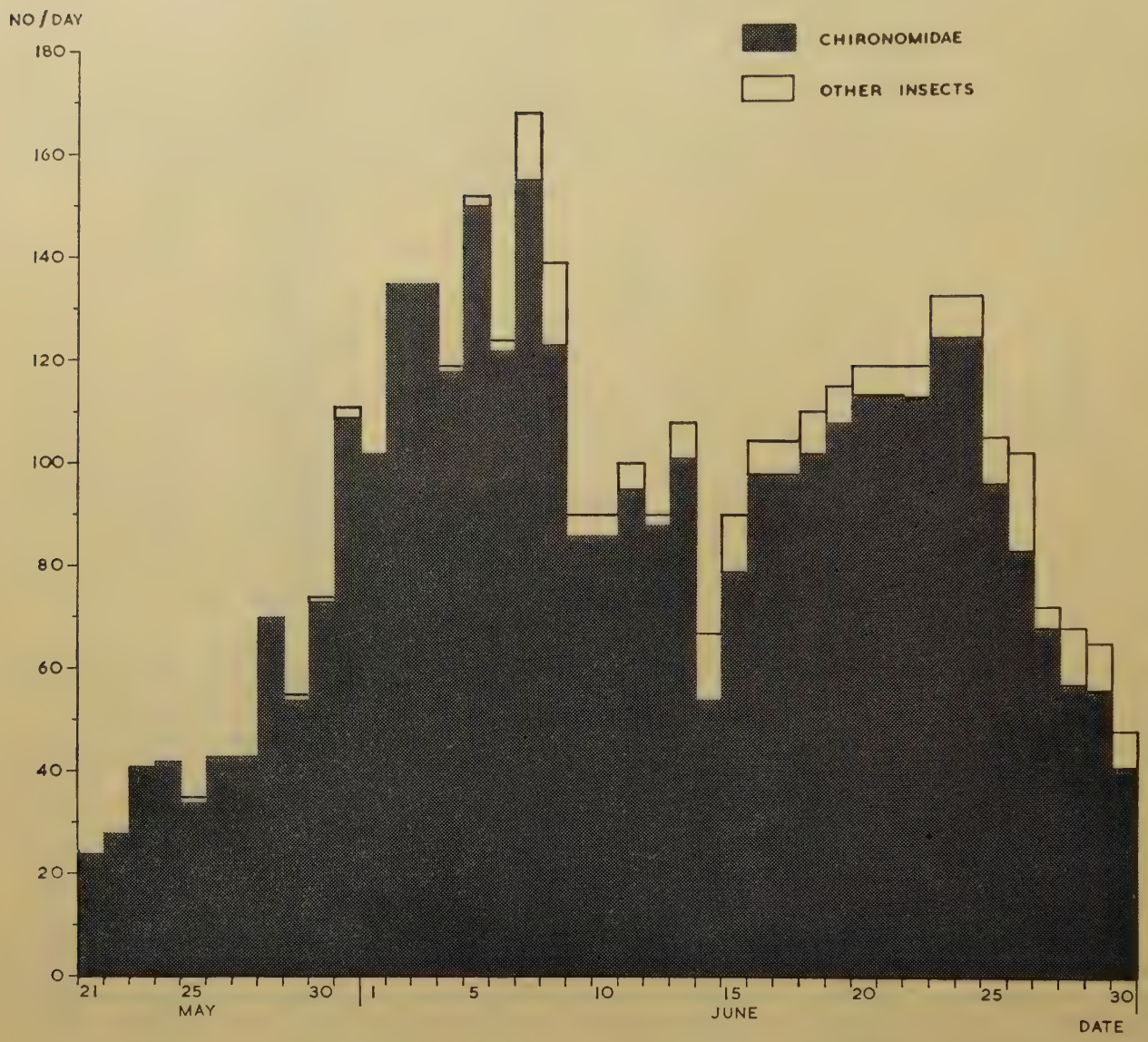


Fig. 6 Variation in the daily catch from 5 sq. ft at site 3.

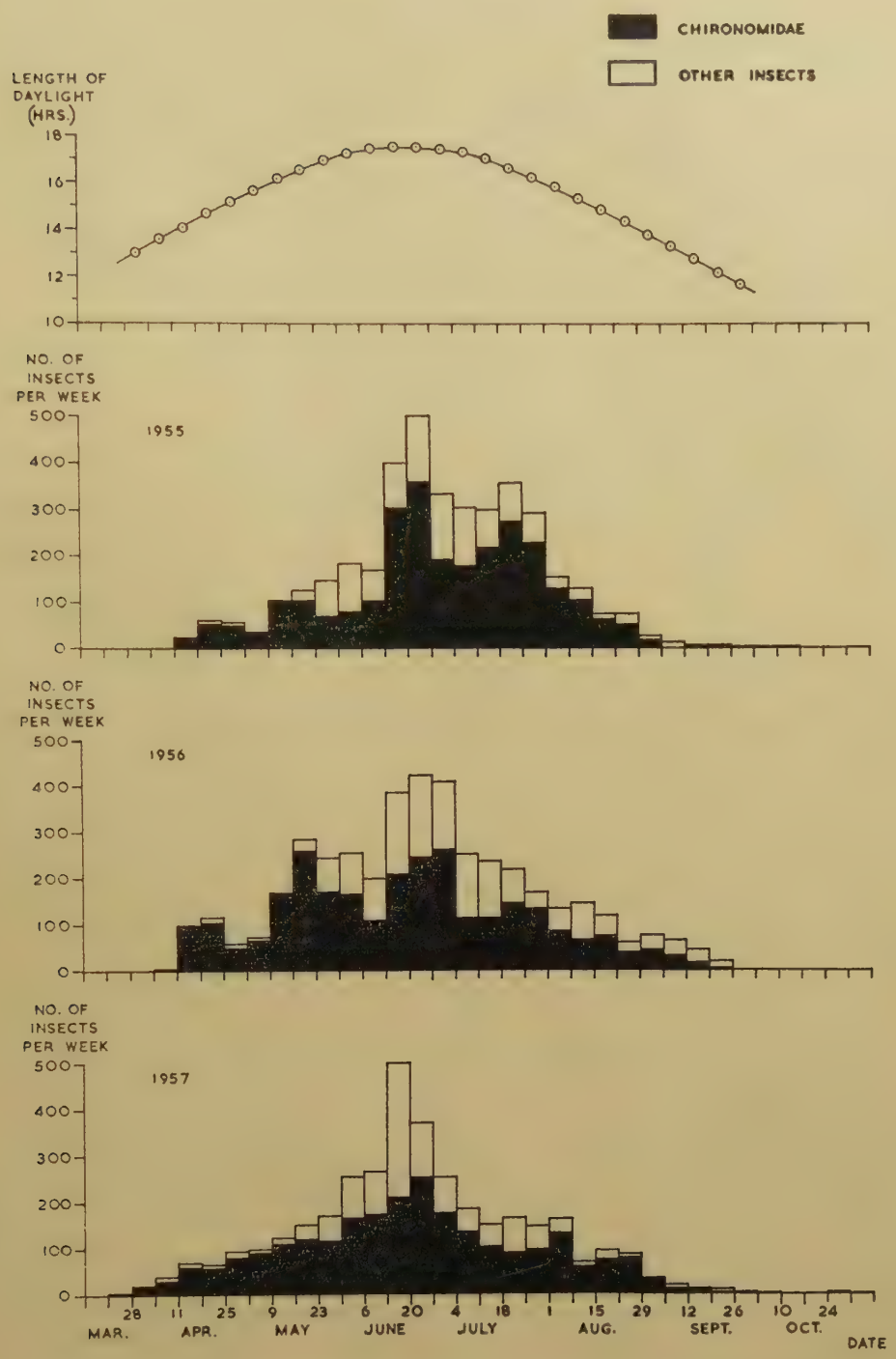


Fig. 7 Seasonal variation in emergence at site 1. The weekly periods in 1956 are two days ahead of those for the other years.

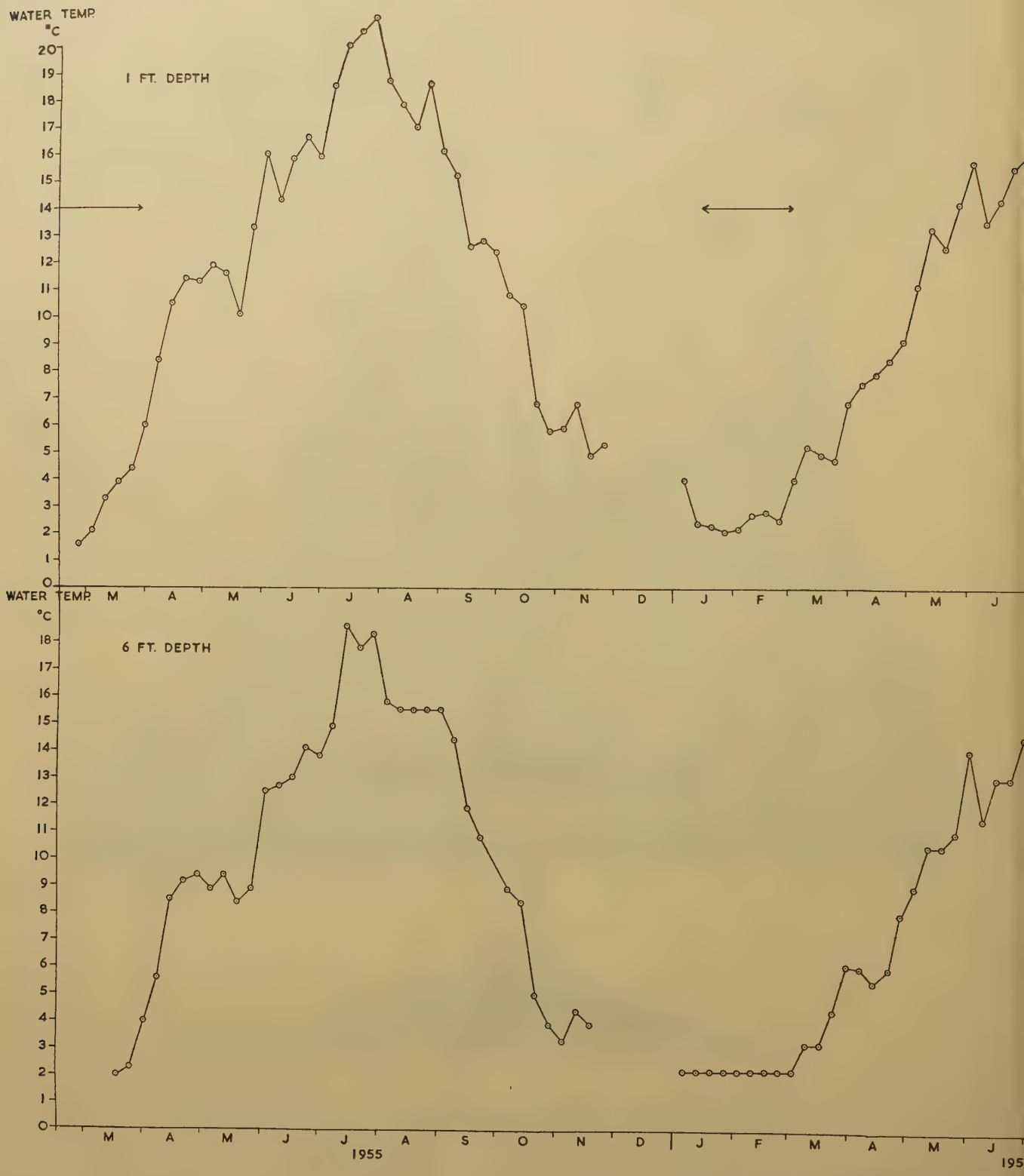
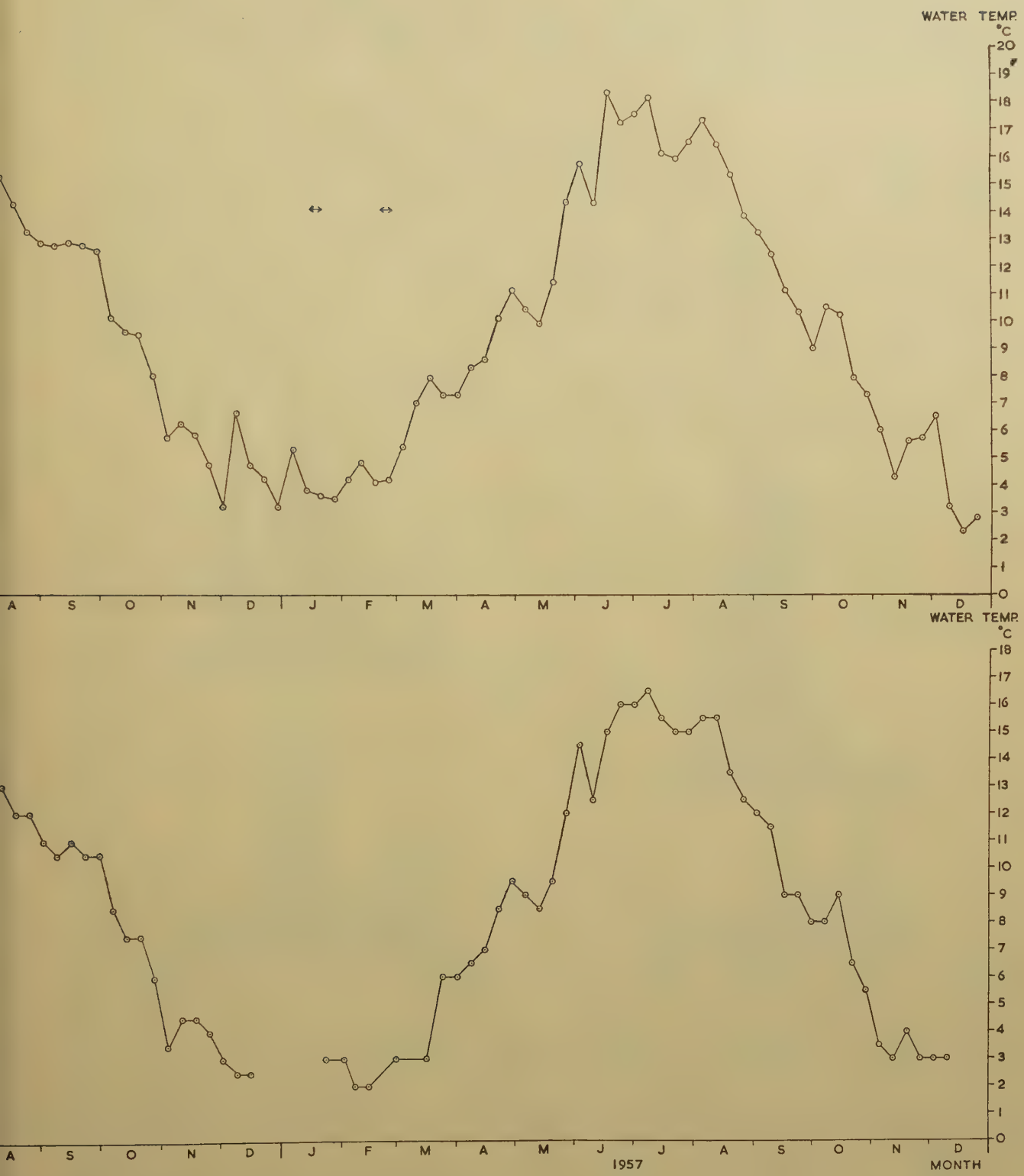


Fig. 8 Seasonal variation in water temperature in shall



leeper water. Periods of ice cover indicated by arrows.

the other sites it is useful to compare the most abundant species over similar periods in different years (Table 4). The most common species are given in their order of emergence within each period. From the end of May to beginning of August different species were most abundant in each year but from August onwards *Cloëon simile* was most common in all years.

TABLE 4

The most Common Species of Insects other than Chironomidae composing the Emergence Peaks at Site 1

Period	1955	1956	1957
End May—Mid June	Cloëon simile	Cloëon simile Leptophlebia vespertina	Leptophlebia vespertina Chaoborus flavicans Ceratopogonidae
Mid June—Mid July	Cloëon simile Leptophlebia vespertina Athripsodes aterrimus Caenis horaria	Cloëon simile Caenis horaria	Ceratopogonidae Athripsodes aterrimus Enallagma cyathigerum Cloëon dipterum Leptophlebia vespertina
Mid July—Beginning August	Ceratopogonidae Cloëon simile Mystacides azurea	Caenis horaria Athripsodes aterrimus Triaenodes bicolor	Triaenodes bicolor Cloëon simile
Beginning August onwards	Cloëon simile	Cloëon simile	Cloëon simile

The total number of insects emerging in July 1955 at site 1 was higher than in the other two years; 36% of the total emergence taking place in that month compared with 23·7% in 1956 and 21·4% in 1957. This may be related to the exceptionally fine weather and higher water temperatures in July 1955.

In all years the emergence rate had fallen to a very low level by the middle of September. The water temperatures at this time were still well above the temperature at the beginning of the emergence period in the spring.

The weekly pattern of emergence at site 3 is shown in Fig. 9. The time of capture of the first insect varied from 28th March to 11th April and the numbers emerging remained small until the weeks commencing 11th April 1955, 16th April 1956 and 11th April 1957 when they rose above 20 per week. These dates coincided with the time at which the water temperature rose above 6·5°C. The seasonal pattern varied considerably over the three years. The maximum emergence rate in each year occurred during the first half of June, 43·9% of the total emerging in that month in 1955, 53·4% in 1956 and 45·2% in 1957. The week of maximum emergence in all years occurs when the water temperature is still rising, see Fig. 8.

The pattern of emergence at this site follows the rise and fall in the numbers of *Tanytarsus* spp. and *Lauterborniella orophilus*. In 1955 there are three pronounced peaks during the emergence period, that in the middle of May caused by the emergence of *Tanytarsus samboni*, that in the second week of June, caused by the emergence of the first generation of *Tanytarsus glabrescens* (?) and by *Lauterborniella orophilus* and that in the second week of August caused by the emergence of the second generation of *Tanytarsus glabrescens* (?). In 1956 there is only one pronounced maximum occurring at the end of May and beginning of June when the first generation of *T. glabrescens* (?) reached a maximum a week earlier than in 1955. *Tanytarsus samboni* reached a maximum in the week 14th-21st May but this was masked by the emergence of *Lauterborniella orophilus* the maximum emergence of which occurred from 21st-28th May, nearly three weeks earlier than in the previous year. The total number of insects emerging therefore increases steadily throughout May. The second generation of *Tanytarsus glabrescens* (?) emerged in the greatest numbers between 6th and 20th August but the total was much reduced in comparison with 1955. During 1957 two pronounced peaks occurred. The maximum emergence of the first generation of *T. glabrescens* (?) was spread over the period 30th May to 27th June and this species and the maximum of *Lauterborniella orophilus* made up the bulk of the emergence in the week 30th May-6th June when the highest total emergence rate occurred. The second generation of *Tanytarsus glabrescens* (?) reached a maximum in the week 8th-15th August and caused the August peak in total emergence. The emergence of *T. samboni* was very small in May, 1957, the maximum emergence occurring in the period 9th-23rd May. The

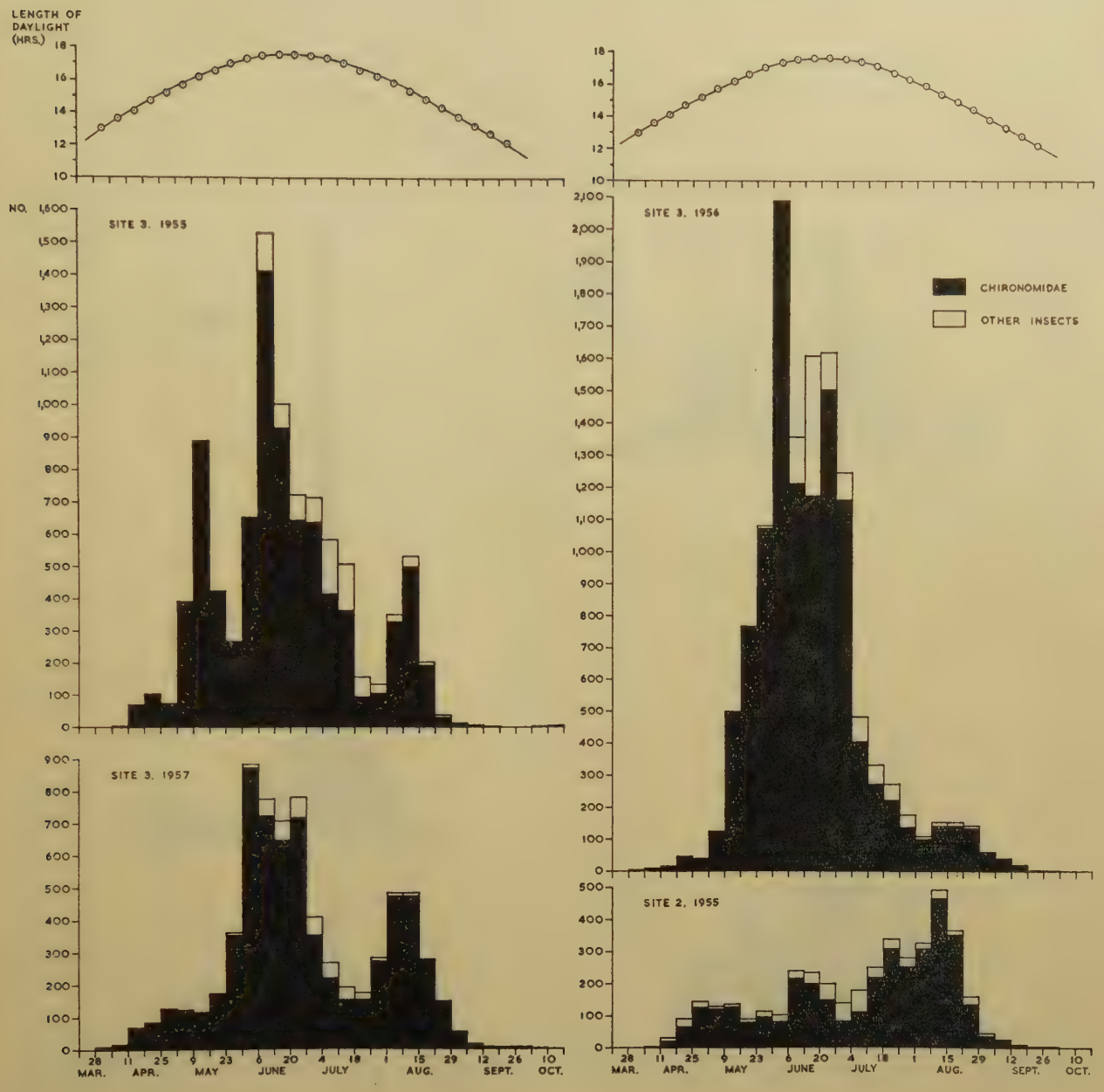


Fig. 9 Seasonal variation in emergence at sites 2 and 3. The weekly periods in 1956 are two days ahead of those for the other years.

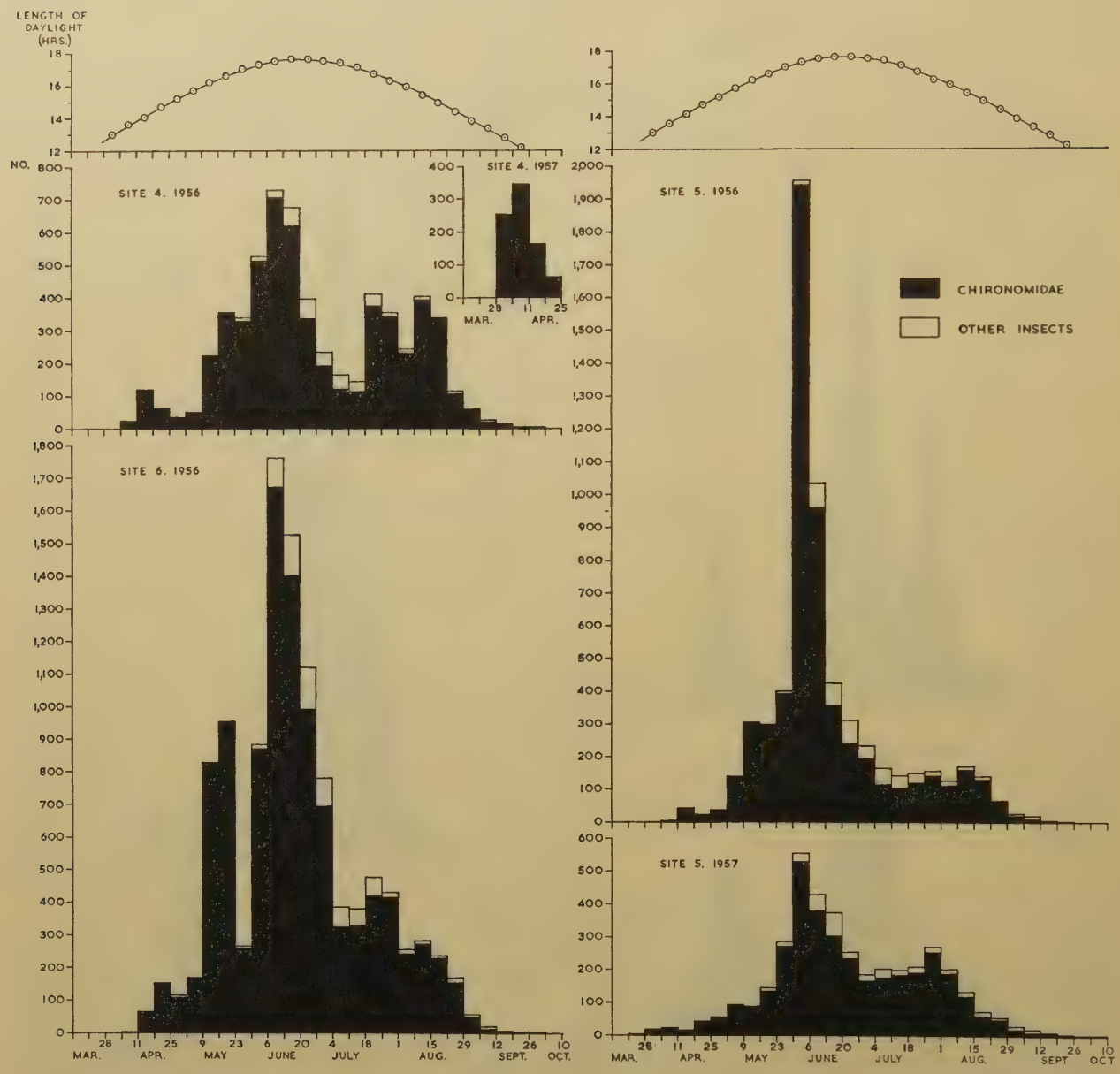


Fig. 10 Seasonal variation in emergence at sites 4, 5 and 6. The weekly periods in 1956 are two days ahead of those for the other years.

seasonal pattern of total emergence varied considerably from year to year due mainly to variation in the magnitude and time of emergence of the three species mentioned. For example, the time of maximum emergence of *Lauterborniella orophilus* varied over a period of three weeks, and the total numbers emerging varied from 1,049 in 1955 to 2,238 in 1956.

The emergence rate declined rapidly at the end of August each year, doing so slightly earlier in 1955 than in the other years. It had fallen to below 20 insects per week by the week beginning 29th August, 1955, 10th September, 1956 and 5th September, 1957.

The seasonal emergence at the other deeper water sites (4, 5 and 6) during 1956 is shown in Fig. 10. The general pattern of the emergence is similar to that at site 3. Emergence commenced at the beginning of April, the maximum emergence rate occurred at the beginning of June, and the emergence rate declined rapidly in the latter half of August with a few insects continuing to emerge until the end of September. The emergence maxima were caused, however, by different species from those at site 3, the species emerging being associated with the *Myriophyllum spicatum* at site 4, *Potamogeton natans* at site 5 and *Elodea canadensis* at site 6. At site 4 the small peak in mid-April was due almost entirely to the emergence of *Chironomus anthracinus*. The maximum at the beginning of June was composed mainly of *Chironomus* (*Harnischia*) *krusemani* Goetgh., *Tanytarsus glabrescens* (?), and *Psectrocladius psilopterus* in that order of importance, the rise in late July comprised several species of which *Ablabesmyia monilis* L. and *Psectrocladius* spp. were the commonest, and the peak from 6th-13th August was made up almost entirely of *Psectrocladius psilopterus*. A comparison of emergence in April 1956 and April 1957 shows the variation which can take place in the rate of emergence from year to year. Over this period 145 *Chironomus anthracinus* emerged in 1956 compared with 746 in 1957. This may have been associated with the decay of macrophytes during the winter. In the winter 1955-1956 *Myriophyllum spicatum* remained green and healthy whereas in the following winter it turned brown and decayed. The maximum number of *Chironomus anthracinus* emerged a week earlier in 1957 in relation to the warmer water temperature. The occurrences of *Psectrocladius psilopterus* and *Chironomus* (*Harnischia*) *krusemani* are the first records of these species from the British Isles.

A trap was operated at site 4 from 30th June onwards in 1955. There was no rise in numbers in mid-July although the species which caused this rise in 1956 were emerging, but in smaller numbers. The August peak was of about the same magnitude as in the following year but occurred a week earlier.

The emergence rate at site 5 during 1956 increased rapidly during May and reached a maximum in the week 28th May to 4th June when 1,837 *Psectrocladius psilopterus* emerged from 4 sq. ft. The numbers emerging decreased during June and remained between 100 and 175 per week from the end of June to mid-August, after which emergence rate decreased to a very low level, and few insects emerged during September. In the warmer spring of 1957 emergence commenced a week earlier but reached a maximum in the same week as in 1956 although only 291 *P. psilopterus* emerged compared with the very large number in 1956. There was a secondary rise in emergence rate from 25th July to 1st August, when the maximum emergence rate of *Tanytarsus tenuis* Meig. occurred, after which the number of insects emerging decreased to a low level by the beginning of September. A few insects emerged up to the end of October. A trap was operated at this site from 9th August, 1955 onwards and similar results were obtained for the end of the emergence period in that year.

At site 6 the maximum emergence rate again occurred in the first half of June when the maximum emergence of *Tanytarsus glabrescens* (?) took place. The May peak was made up chiefly of the first generations of *Tanytarsus samboni* and *Psectrocladius psilopterus*. *Tanytarsus samboni* was more common at this site than at any of the others and it is only at site 6 that the emergence rate of the total fauna in mid-May 1956 was higher than that at the end of May. As at the other sites most of the insects emerged between the beginning of April and the end of August and the emergence rate declined rapidly during August.

The seasonal emergence at the shallow site 2 in 1955 is shown in Fig. 9. This site is strikingly different from the other sites in that the maximum emergence rate occurred at the beginning of August but similar in that after this the numbers emerging decreased sharply to a low level by the beginning of September. The August maximum was composed of considerable numbers of several species of which the second generations of *Chironomus* (*Cryptochironomus*) *edwardsi*, *Tanytarsus glabrescens* (?) and *Tanytarsus excavatus* Edw. were the most common insects in the order given. It is noteworthy that *Ablabesmyia cingulata* was the most common species at site 2 although not forming the bulk of the larger peaks. At the other

sites the commonest species was present in such large numbers that the seasonal maximum for all emergence usually coincided with the maximum for that species. At site 2 *Chironomus* (*Cryptochironomus*) *edwardsi,* which was the commonest insect at the time of the August maximum, was the second most common species.

At all sites the emergence period extends from the beginning of April to the beginning of September with a rapid decline in numbers emerging during late August and a few 'stragglers' emerging during September and, in some years, well into October. The time of maximum emergence varied between different sites, at the shallow water sites 1 and 2 maximum emergence rates occurred in late June and early August respectively and at all the deeper water sites at the beginning of June. In spite of the similarity in the time of the maximum emergence from deeper water the composition of the maxima varied in relation to the abundance of different species in the different habitats. The general pattern of emergence at the same site was similar from year to year, but there was variation in the total number of insects emerging at any given time from year to year, due to variation in numbers and or slight shifts in the time of maximum emergence of individual species. The fluctuations in numbers of a species were sometimes considerable, giving large differences in the size of the maximum in successive years.

The seasonal pattern of the changes in emergence rate at site 1 was similar to that found by Miller (1941) at one and three metres in Costello Lake and that at site 2 to the findings of Judd (1953) at Dundas Marsh. However the seasonal maxima did not coincide precisely from year to year as at Costello Lake. None of the Loch Dunmore sites were comparable with Winona Lake where Scott and Opdyke (1941) found little variation in emergence rate from June to early September at 3-9 m. The occurrence of the maximum emergence rate from the deeper water sites at Loch Dunmore at the beginning of June was earlier than that found by workers in other areas.

At all sites the emergence rate during the maximum emergence period was higher in 1956 than in 1955 or 1957. This may have been related to the warm water conditions and exceptionally sunny weather during the late summer of 1955 when many of the insects which would emerge in 1956 were in the egg or larval stages. At each site except site 3 emergence started a week to a fortnight earlier in 1957 when the water temperature was higher, both in deep and shallow water, during January, February and March, than in the other years. In shallow water the difference was greater than in deeper water, the temperature was 1·5-2°C higher and correspondingly the advancement of the emergence period was greatest at site 1. Both Ide (1940) and Miller (1941) found that the beginning of the emergence period was advanced by a warm spring.

The seasonal variation in the length of daylight, between sunset and sunrise, is shown on Figs. 7, 9 and 10. The pattern of emergence coincides more closely with the length of daylight curve than with the temperature curves in Fig. 8. The maximum emergence rate occurs during the period of longest daylight and emergence rate increases and decreases with increasing and decreasing length of day.

A criterion of more or less than 20 insects emerging in a week was used to mark respectively the beginning or end of the main emergence period at each site. Treating the deeper and shallow water sites separately (Table 5), in shallow water emergence commenced when the water temperature was 7·2-10·6°C (mean 9·1°C) and the length of daylight 13·0-14·1 hrs (mean 13·8 hrs) and ended when the water temperature was 12·3-16·1°C (mean 14·1°C) and length of daylight 12·8-13·8 hrs (mean 13·3 hrs). In the spring of 1955, when emergence at sites 1 and 2 commenced when the water temperature was 10·6°C, the average water temperature rose very rapidly from 4·4-10·6°C in three weeks, and the higher temperature at the commencement of emergence than in the other years was probably a result of this unusually rapid rise in water temperature. At the deeper water sites emergence commenced when the water temperature was 5·5-7·0°C (mean 6·2°C) and the length of daylight 13·6-14·7 hrs (mean 14·0 hrs) and ended when the water temperature was 10·5-15·5°C (mean 11·8°C) and the length of daylight 13·3-14·4 hrs (mean 13·7 hrs).

The mean water temperatures are calculated only from the years when data were available for the beginning and end of emergence in the same year. In shallow water there was a difference of 5·0°C and in deeper water a difference of 5·6°C between the mean temperatures at the beginning and end of the emergence period. Temperature appears to limit emergence at the beginning of the emergence period since last instar nymphs and larvae, of insects emerging early in the year, emerged as adults when brought into the laboratory during January and February and kept under normal daylight conditions. This was

TABLE 5

Average Water Temperature (W.T.) and Length of Daylight for the Week when Emergence rose above 20 Insects/Week and for the last Week when Emergence remained above 20 Insects/Week

Site	Year	Beginning of Emergence		End of Emergence	
		W.T.	Length of Daylight	W.T.	Length of Daylight
		(°C)	(hrs)	(°C)	(hrs)
1	1955	10·6	14·1	16·1	13·8
1	1956	7·9	14·1	12·6	12·8
1	1957	7·2	13·0	12·3	13·3
2	1955	10·6	14·1	15·2	13·3
3	1955	6·8	14·1	15·5	14·4
3	1956	6·0	14·7	10·5	13·3
3	1957	7·0	14·1	12·0	13·8
4	1955	—	—	15·5	14·4
4	1956	6·0	13·6	10·5	13·3
4	1957	6·0	13·0	—	—
5	1955	—	—	15·5	14·4
5	1956	5·5	14·1	11·0	13·8
5	1957	6·5	13·6	12·0	13·8
6	1956	5·5	14·1	11·0	13·8

demonstrated by bringing nymphs of *Leptophlebia marginata, Cloëon simile* and *Caenis horaria* into the laboratory and maintaining the water temperature at 10°C. Corbet (1954) found that nymphs of Odonata entering their last instar in late summer went into a diapause until the autumn and were then unable to emerge until the temperature rose above a threshold the following spring.

The threshold temperature for the commencement of emergence in shallow water at Loch Dunmore was about 7·5°C and in deeper water about 6°C. Chironomids living below the thermocline in deep lakes can emerge at lower temperatures as Miller (1941) found that, in Costello Lake, ten species emerged from 17 m depth where the water temperature at the bottom was between 3·9 and 4·4°C during the summer. Surface temperatures were, of course, higher and although the low water temperature did not prevent pupation the warmer surface temperatures may have been necessary for the actual process of emergence. The seasonal emergence of these species from deep water, where temperature and light intensity fluctuated less than in shallow water, tended to extend over a long period and show no marked maxima.

Thus the evidence indicates that water temperature is not limiting insect emergence at the end of August. Some insects did emerge during September and October but they were few in number and sporadic in their emergence. At the end of the decline in late August the length of daylight is similar to that at the beginning of emergence and the shorter length of day during September and October may therefore be the factor which restricts emergence. This may retard the development of late instar larvae either directly, through an effect upon the metabolism of the insects, or indirectly through its effect on the growth of algae and macrophytes. The former supposition may explain why the carnivorous forms do not emerge during this period. On the other hand, the whole population may have depleted itself naturally by emergence so that the time interval before autumn is too short to allow the young larvae to reach a stage at which they can pupate. Further experimental work on the factors limiting emergence in late summer is necessary.

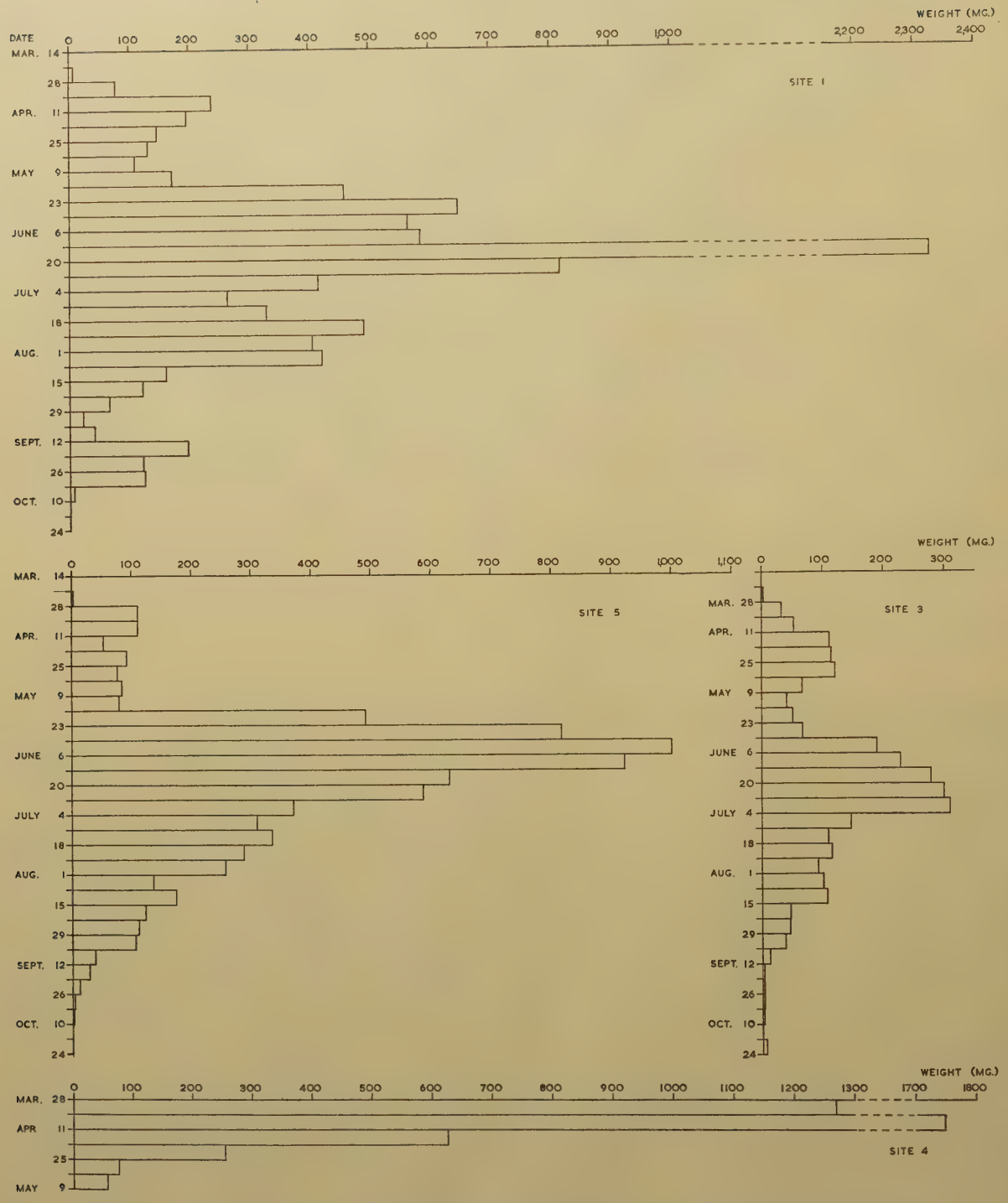


Fig. 11 Seasonal variation in the total weight of insects emerging from an area of 5 sq. ft.

SEASONAL VARIATION IN WEIGHT

It is felt that the differences in the size of insects associated with weed and those associated with the bottom mud in lochs of this type is not generally emphasised in fish feeding studies. It has already been shown that, although the number of insects caught at site 3 was higher than at the other sites, the total weight of insects leaving the water surface here was the least due to their small size. The importance of taking weight into consideration, in order to compare the amount of food which is available to fish in different habitats at different times of year, is shown when the seasonal variation in weight is compared with the seasonal variation in numbers. The seasonal fluctuations in weight during 1957 are shown in Fig. 11.

At site 1 chironomids formed about 70% of the total catch by numbers but the other insects were so much heavier that the seasonal variation in the weight of the total fauna followed variation in the number of these other insects. Whereas when considering numbers the seasonal emergence rate rose gradually to a single maximum in late June (Fig. 7), the seasonal change in the weight of the insects emerging was much less regular. At the beginning of April *Microtendipes chloris* v. *lugubris*, then the commonest insect, and a few of the larger *Leptophlebia marginata* contributed equally to the weight peak. A rapid rise in the weight of the insects emerging at the end of May was associated with the emergence of *Leptophlebia vespertina* and five *Pyrrhosoma nymphula* Sulzer. That the weight maximum in mid-June coincided with the seasonal maximum in numbers was to some extent fortuitous since over half of the weight of the insects caught was due to 38 *Enallagma cyathigerum*. The Ceratopogonidae, which contributed the highest numbers at this time, were a negligible proportion of the weight. Much of the increase from mid-July to mid-August was produced by *Cloëon simile* and *Triaenodes bicolor* which were then the most numerous 'Other Insects', but most of the weight was contributed by a much smaller number of *Limnephilus marmoratus*. The considerable weight of insects emerging from the middle of September to the beginning of October, when very few insects were emerging, was produced almost entirely by seven *Anabolia nervosa* Curt. which emerged over a period of three weeks.

At site 3 there was a small peak in the weight of insects emerging in the latter part of April when the large chironomids *Procladius simplicistylus* Freeman and *Chironomus anthracinus* emerged. The greatest weight of insects emerged during June, when the numbers emerging were greatest, but whereas the maximum number emerged in the first week in June, the maximum weight occurred in the week extending from 27th June to 4th July. Over the whole month *Tanytarsus glabrescens* (?) emerged in large numbers but in the last two weeks the total weights were increased due to the emergence of *Procladius choreus* and *Caenis horaria* both of which are considerably heavier. The high emergence rate at the beginning of August is not evident in the histogram of the seasonal variations in weight due to the small size of the *Tanytarsus glabrescens* (?) which by number composed most of the emergence over that period.

At site 4, where results are only available for the beginning of the season when the large emergence of *Chironomus anthracinus* occurred, the weight of insects in the second week of April was second only to the maximum weight of insects emerging at site 1 in mid-June. The weight per week rose and fell in step with the numbers of *C. anthracinus*.

The maximum weight of insects at site 5 coincided with the emergence of the maximum number of insects between 23rd May and 13th June, when 567 *Psectrocladius psilopterus* and 21 *Limnephilus marmoratus* contributed about equally to the weight of insects captured. There was a general decline in the weight of insects emerging from early June onwards, although there was an increase in numbers emerging at the end of July (Fig. 10), when the small *Tanytarsus tenuis* emerged.

The seasonal fluctuation in weights during 1957 showed that the greatest weight of insects emerged during April and from the middle of May to the end of June. At all sites the weight of insects produced at the water surface at the beginning of May was low. From the end of June onwards the greatest weight of insects emerged at the shallow weedy site and this was the only site where an appreciable weight of insects emerged in September.

NUMBER OF SPECIES AND WATER TEMPERATURE

Miller (1941) found that seasonal variation in the number of species of chironomids emerging was 'directly correlated with temperature changes'. A small number of species were caught in spring, the maximum in mid-July and then there was a decline in the number of species to the freeze-up in November. In two summers the highest average temperatures coincided with the greatest number of species. Judd (1953) also found that the seasonal variation in the number of species emerging correlated directly with changes in temperature.

The number of species of chironomids emerging each week from Loch Dunmore sites 3 and 5, in 1957, and the average weekly minimum temperature at six feet depth are shown in Fig. 12. The number of species emerging increased from the first emergence in late March to a maximum in June and July and decreased to the last emergence in mid-October. The number of species caught per week follows the increases and decreases of temperature. The fall in temperature in early May was accompanied by a decrease in the number of species emerging, and the number of species declined quickly when the temperature, which had remained at or above 15°C from mid-June to early August, fell steadily during August.

The number of species emerging per week at sites 3 and 5 are only complete for 1957, but it was possible to compare the results from 1956 and 1957 at site 1 with the average weekly temperatures in shallow water (Fig. 13). Again the number of species emerging follows the changes in water temperature so that the differences in the form of the temperature curve in the two years were accompanied by similar changes in the form of the curves showing the number of species emerging. As at sites 3 and 5 the fall in temperature in early May, 1957 was followed by a decrease in the number of species emerging. In 1956, when there was no fall in water temperature at the beginning of May, the number of species of chironomid emerging at this time continued to rise.

The average water temperature sequence in 1957 was not a typical one in that the highest weekly average temperature occurred between 13th and 20th June. In 1955 and 1956 the highest weekly temperatures occurred in the second half of July. The highest number of species emerging per week occurred earlier in 1957 than in 1956 which correlated with the earlier high water temperatures, and there was a dip in the number of species emerging in July, 1957, which coincided with a fall in the water temperature. If the number of species emerging per week was determined by the length of daylight, maximum numbers of species should be caught in the second half of June in all years.

It would appear that in Loch Dunmore the number of species of chironomid emerging per week can be correlated directly with changes in water temperature which agrees with the findings of Miller (1941) and Judd (1953).

DISCUSSION

The results show that emerging insects are available to fish in quantity from the beginning of April to mid or late August. By number the chironomids predominate over the whole period although by bulk they are most prominent in April. The species of chironomid emerging in April emerge over the middle of the day whereas from mid-May onwards the maximum emergence rate occurs just after sunset. From May onwards Ephemeroptera and Trichoptera emerge in considerable numbers and compose the greater part of emergence by weight in shallow water although chironomids are of greater importance by weight in deeper water. In other lochs, where late summer and autumn emerging species of caddis, such as *Limnephilus lunatus* and *Anabolia nervosa,* are abundant, these may extend the availability of emerging food organisms into September and October. As these insects are large their availability at this time would be of considerable importance if utilised by trout. The weights of individual species show that in studies on fish feeding the grouping of food organisms under large group headings such as Trichoptera gives little indication of the relative bulk of different groups which are being eaten. The Trichoptera at

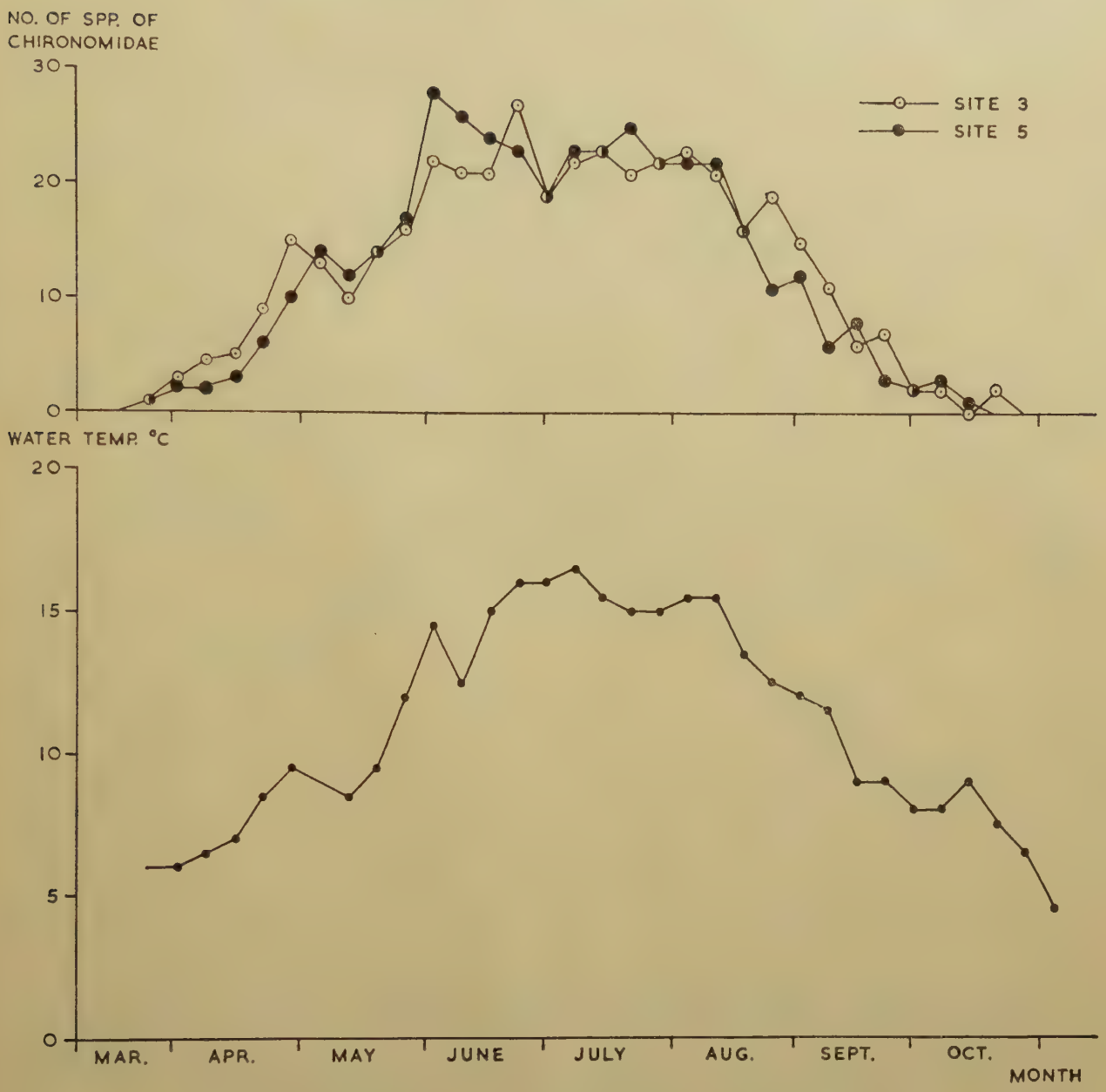


Fig. 12 The number of species of Chironomidae per week caught at sites 3 and 5 in 1957 in relation to water temperature.

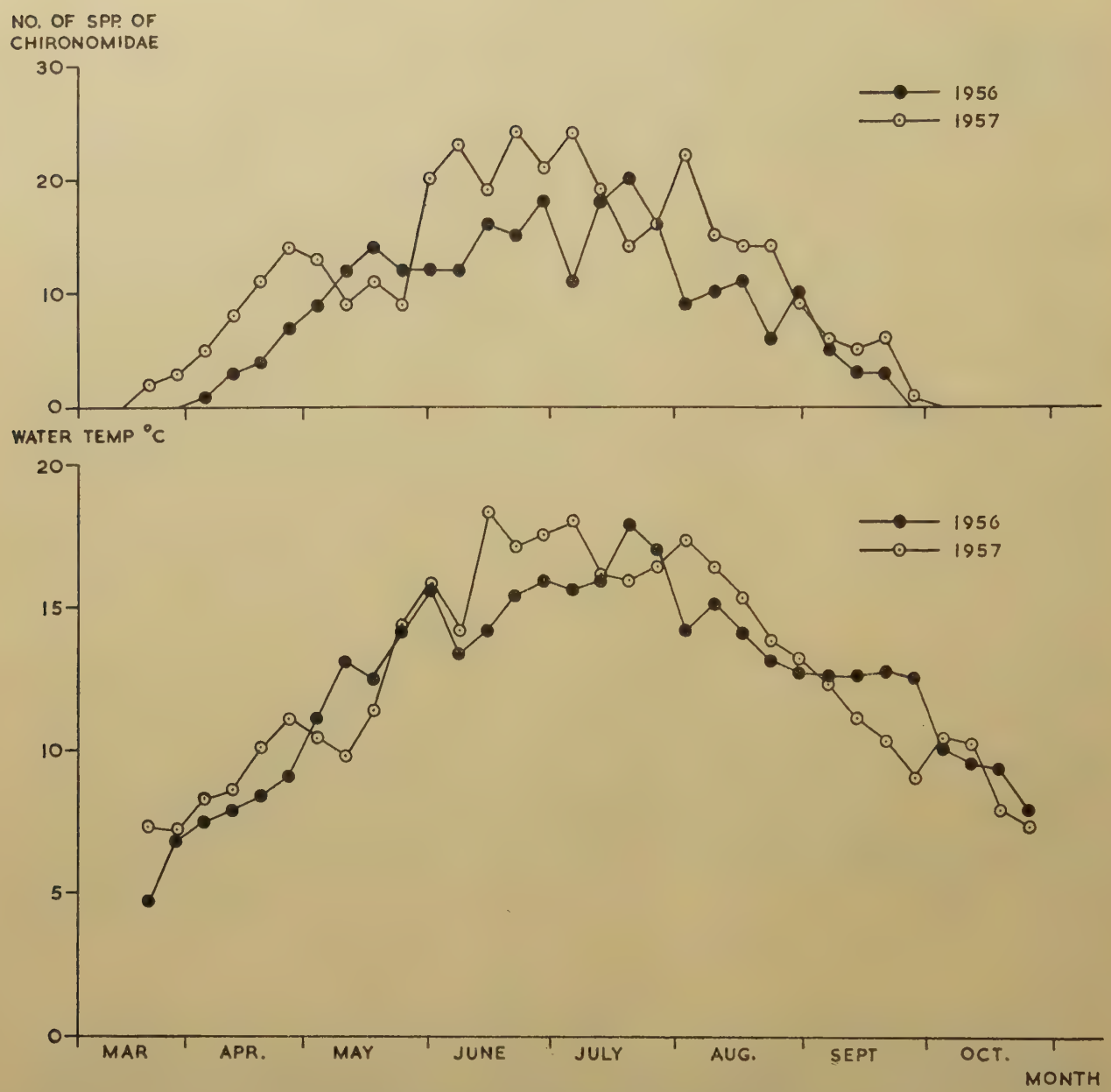


Fig. 13 The number of species of Chironomidae per week caught at site 1 in 1956 and 1957 in relation to water temperature.

Loch Dunmore, for instance, showed a difference of over one hundred times in weight between the larger and smaller species and the larger chironomid midges were considerably bigger than the small caddis. Thus it is necessary, among other factors, either to stipulate the species or the size of the insect when considering the value of different insects as fish food.

Although this study has been confined to one body of water it is useful to relate the results to those of workers on the feeding of brown trout in other areas, reserving the possibility that differences in seasonal emergence rate may be found in other waters. In general the pattern of trout feeding in lakes can be summarised as follows: feeding near or on the bottom during the winter months on permanent members of the bottom fauna; feeding on emerging insects, particularly chironomids, in the spring and early summer; and feeding on wind blown insects, mainly of terrestrial origin, in the late summer (Allen, 1938; Nilsson, 1955 and Campbell, 1955). Frost and Smyly (1952), studying trout feeding in a moorland fish pond from March to September, found that chironomid pupae were the main food in April and May and remained an important food during June, July and August and that *Caenis* nymphs were taken in June and July. Comparing the findings of Frost and Smyly with the results from Loch Dunmore, the stomach contents of the trout from the moorland fish pond were closely related to the availability of different insects in mid-water as pupae and last instar nymphs which were rising to the surface to emerge. The complete preponderance of chironomid pupae in the trout stomachs in April and May is probably related to the high production by weight of the large chironomid species emerging at this time and to the relatively small numbers of other species of insect emerging. Also, at this time of year the main emergence is occurring at midday when the pupae are presumably easier to see than after sunset. In June and July when the trout are feeding heavily on *Caenis* nymphs during the evening they may well be satiated by the time the main emergence of chironomids commences after sunset.

Campbell (personal communication) has found that in Loch Tummel during April and May the trout are feeding chiefly on the large pupae of *Chironomus* spp. and the emerging nymphs of *Leptophlebia marginata* and in June on the small green pupae of *Tanytarsus* spp. In lakes where *Leptophlebia marginata* is more common than in Loch Dunmore the appearance of this early emerging mayfly supplements the feeding on chironomids in April and May. From July onwards chironomid pupae are not taken in large numbers by Loch Tummel trout.

The trout at Loch Dunmore were observed to rise very freely in the middle of the day in April, when *Chironomus anthracinus* emerged, but later in the summer very few trout were seen to rise over the midday period. The stomachs of fourteen trout, weighing from $1\frac{3}{4}$ oz. to 26 oz., caught in April contained an average of 89 *C. anthracinus* pupae the numbers varying from 28 to 174 per fish. Campbell (personal communication), in laboratory experiments with brown trout, has shown that the main seasonal increase in food intake and growth commences in the spring when the water temperature rises above 5°C. The water temperature had risen above 5°C just before the spring feeding on *C. anthracinus* commenced, showing the importance of this large weight of chironomid pupae at this time of year. Although this heavy feeding on chironomid pupae may only continue for about six weeks its importance to the trout may be much greater than that of large organisms such as *Gammarus, Asellus* and *Limnaea* which may form the bulk of the winter feeding when the temperature is low.

In Windermere Allen (1938) found that from July to September the trout fed almost entirely on terrestrial insects taken at the water surface. He states that 'The results suggest that when all classes of food are available the trout will feed on the surface rather than on the bottom and that, if no surface food is present, they will feed on the temporary bottom fauna rather than on the permanent bottom fauna'. Trout caught during the daytime from Loch Dunmore in June and July were found to contain very few chironomid pupae although chironomid emergence rate remains high until the middle of August. It may therefore be that the Dunmore results confirm Allen's observations. On the other hand the bulk of chironomid emergence from June onwards occurs after dusk and it is unlikely that many workers have sampled fish regularly at midnight. It is felt that the present results indicate that in order to obtain a true picture of a trout's diet during the summer months four samples of the trout should be caught per day, in the morning, afternoon, evening and about midnight since at summer temperature digestion may be too rapid for a sample taken at one time of the day to suffice. Stuart and Forsyth (personal communication), in some preliminary experiments on the rate of digestion of food by brown trout, found that when they were fed on *Gammarus* the food first passed into the intestine 8 hours after

ingestion although complete passage through the fish took about 25 hours at 14°C. It may well be that the small numbers of emerging insects found in the stomachs of trout from July onwards, by some workers, is related to daytime sampling. There is obviously great variation in trout feeding from one lake to another, dependent upon the specific composition of the invertebrate fauna. For instance at Loch Moraig, Perthshire, which contains a very large population of *Cloëon simile*, there is a regular midday rise of trout to the emerging nymphs of this insect from May to September. As already mentioned, trout feed vigorously on the nymphs of *Caenis horaria* between 1800 and 2200 hrs in June and July, yet in lochs where this insect is not present there may be few emerging insects at this time of day.

There may also be a big variation in the seasonal feeding habits of fish in the same lake from year to year. Nilsson (1955) for Lake Blåsjön has shown considerable variation in the pattern of feeding of trout and char from one summer to the next. This is probably related to variation in availability of the food organisms from year to year. There were big differences in the maximum emergence rate from Loch Dunmore in successive years, due to differences in the abundance of individual species and to slight variations in the time of the maximum emergence rate of individual species. This leads to the maxima of abundant species coinciding in some years and being separated by as long as a fortnight in other years. This would cause variation in the food organisms available at a particular time of year from one area. In June and July when a large number of species of insect were emerging considerable variation in the species fed upon might be expected. Also the seasonal distribution of a fish population may vary in different years in relation to the available food supply.

The little information that is available indicates that there may be considerable differences in the times of emergence of an insect species with relatively small differences of latitude. Mundie (1957) found that in London storage reservoirs *Parachironomus vitiosus* Goetgh. had two generations and he concluded that *Polypedilum nubeculosum* Meig. had three generations a year. In comparable depths of water these species are both univoltine at Loch Dunmore. It is probable that altitude differences between lakes situated in the same geographical area cause similar differences in the number of generations of insect species common to those lakes. Thus big differences in the time when certain foods are available to fish may exist between lakes. Similarly in large lakes differences in the time of emergence of the same species have been found at different depths, the insects emerging earliest in the shallowest part of their range (Miller, 1941; Brundin, 1949). Miller found that 'Such a behaviour is typical of all species living above the thermocline'.

Various workers have found that it is common in salmonid fish for each stomach to contain a high proportion of one food organism (Southern, 1935; Allen, 1938; Nilsson, 1955). Nilsson states 'The choice often seems to be very subtle; for example *Heterocope* dominating one stomach, *Holopedium* another, *Heterotrissocladius*-pupae dominating one stomach, *Procladius*-pupae another and the two food objects rarely are mixed though they occur in the fauna at the same time'. The dominant type of food may be governed by the fish's position in the environment when it commences feeding and, having started to feed on one organism, it may continue to 'look' for food of that particular shape, size and possibly with that particular mode of progression. The onset of feeding on this organism may be closely related to its availability. There may also be inherent preferences for different foods. This selective behaviour among salmonid fish indicates the inadvisability of using angling methods as a means of catching these fish for stomach analyses. It is difficult to find a method of catching fish from lakes which is not selective to some degree, but electrical fishing, if it can be adapted to lake conditions, may provide a non-selective means of sampling fish for feeding studies in the future.

van Someren (1940) has studied the evening rise of trout. He states that 'Under favourable conditions the rise can be expected to start 20-30 minutes after sundown. . . . The rise is at its height about 10-15 minutes after starting, and ceases in about 30 minutes with the exception of a few fish which rise sporadically until complete darkness falls'. He considers that 'Light is the most important factor determining when the trout will rise, other factors determining if the trout will rise'. The coincidence of the time of the evening rise with the time of maximum emergence of the Chironomidae suggests that the regular time of emergence of these insects directly determines when the trout will rise. Thus light determines the time of the evening rise of trout indirectly through its effect on the Chironomidae. Since only small numbers of chironomid pupae have often been found in trout stomachs in June, July and August, this again indicates the necessity of sampling about midnight.

The results from Loch Dunmore show that in March and April the highest intensity of emergence is over midday. In May, June, July and August the emergence rate is high just after dusk and in shallow water it is also high over the midday period. During June and July the emergence of *Caenis horaria* causes a high emergence rate in the evening prior to dusk so that the evening emergence period begins earlier. It may well be that fly fishermen fishing lochs of this type at other times of day will be unlikely to catch fish easily.

It remains to consider what steps the results of the emergence studies on Loch Dunmore suggest towards the improvement of trout waters. Of great importance from the point of view of fish production is the greater production of emerging insects over weedy areas compared with nearby areas with little or no plant growth. The weight of insects emerging per sq. ft in a year over *Potamogeton natans* was 2·6 times as great, and that from *Myriophyllum spicatum*, by 9th May, 1·4 times as great as the weight of insects emerging from almost bare mud at the same depth in a year. It is therefore evident that, wherever practicable, weed growth should be encouraged in trout waters. Hasler (1954) increased the plant growth of acid bog lakes by the addition of hydrated lime. The lime had the dual effect of increasing the nutrient materials available for plant growth and clarifying the brown coloured water thus allowing photosynthesis at a greater depth. The increased aeration due to the photosynthesis also allowed rainbow trout to exist in the lake during the hot summer months whereas before the application they were unable to do so. After the initial application Hasler found that smaller amounts must be added each year to prevent the lake from reverting to an acid condition. Waters and Ball (1957) applied hydrated lime and crushed limestone to Stoner Lake, which is a soft-water lake, in the early summer of 1952 and 1953. During 1954 and 1955 *Myriophyllum tenellum* increased markedly over much of the sandy bottom and where this invaded a sampling station there were indications that the standing crop of bottom fauna increased about ten times. Conversely, Wohlschlag (1956) found that the addition of peat to a marl lake produced increased growth of *Chara, Scirpus subterminalis* and *Potamogeton* spp. He tested the effect of four lake soils (light marl, dark marl, sand and peat) separately and in combination under marl lake conditions. Of all these combinations he found that 'The effect of the peat soil alone is consistent and very significantly positive in its effect to produce plant growth'. Deposits of peat in the marl lochs eventually formed rich organic muds. Wohlschlag also showed that the weedy areas of the lake, where peat had been added, supported a much greater invertebrate fauna than the relatively barren marl areas at the same depth. He also found evidence which suggested that the chironomids from the weedy areas were utilised, by small fish and predatory invertebrates, to a greater extent than in the surrounding barren areas.

Barren marl lakes are not common in the Scottish Highlands but small acid lakes with a peat bottom and often supporting a population of very small trout are found commonly. The addition of hydrated lime to lochs where the chemical and physical conditions are suitable would probably produce the favourable soil conditions for plant growth obtained by Hasler, Wohlschlag, and Waters and Ball and thereby increase their capacity to produce trout food.

In lochs which support a rich plant growth an attempt should be made to strike a balance between the requirements of the fish and those of the angler. *Potamogeton natans* with its floating leaves is often a great nuisance to anglers where it covers large areas of water surface and it may be an advantage to replace this species with submerged forms such as *Apium inundatum, Myriophyllum* spp. and *Chara* spp. Where excessive weed growth is hindering angling, attempts should be made to control the weed growth in selected areas either mechanically or chemically, but great care should be exercised in the use of chemical weed killers which, if used in excess, may denude large areas of the bottom.

Although macrophytes are fed on to some extent by the invertebrate fauna and support a certain number of stem and leaf borers, they are also important to the bottom fauna generally in offering a very much increased surface area on which attached algae can grow. It may be possible to achieve a comparable increase in surface area by sinking bundles of heather into the water as a support for attached algae, in much the same way as wattle hurdling is used in fish culture in the tropics. In reservoirs produced because of hydro-electric developments, where there is a daily fluctuation in water level, shallow bays may be emptied of water for short periods. This prevents the development of aquatic plants since they become desiccated during hot, dry weather. During the construction of such reservoirs it may be possible to build a low wall across the mouth of such bays sufficiently high to retain enough water to cover the plants at all times when the level of the water in the reservoirs is lowered. It is well known among anglers

that shallow lochs are usually very good fishing lochs. Shallows are important from the point of view of production of the bottom fauna because first, light reaches the bottom and weeds can grow and second, the rate of turnover of the bottom fauna is much greater there than in deeper water. Borutsky (1939) found that in Lake Beloie *Chironomus plumosus* had two generations a year at 2 m depth, one generation a year at 4 m and, at a depth of 5-7 m, one generation a year in a warmer year but only one generation in 1½-2 years in an unusually cold year. Miller (1941) calculated that the standing population of chironomid larvae in Costello Lake was replaced eight or nine times during the summer in the epilimnion and two or three times in the hypolimnion. Wherever possible, when making new reservoirs where sport fishing is to be taken into consideration, terracing of the shoreline would greatly extend the areas of the shallows thus increasing the potential productivity of the reservoir. A depth of 6-10 ft would be suitable and is also a good depth for fishing.

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SUMMARY

1. Insect emergence was studied at Loch Dunmore, during 1955, 1956 and 1957, by the use of floating emergence traps. Traps were sited over several different types of bottom and vegetation in 6 ft of water and less than 1 ft of water.

2. The traps over deeper water caught two to three times as many insects per sq. yd as those over shallow water. The biggest catches occurred in traps set over areas where the bottom was almost free of vegetation. The catches consisted mainly of Chironomidae, Ephemeroptera and Trichoptera, the Chironomidae forming between 70 and 90% of the total number of insects.

Among the Chironomidae the proportion of Tanypodinae was much higher in traps set over shallow water than in those over the deeper water. The Orthocladiinae, chiefly *Psectrocladius* spp., were most common in traps over deeper water where the bottom was covered with macrophytes and Chironominae, chiefly *Tanytarsus* spp., over deeper water with a mud bottom and little plant growth. The Ephemeroptera were most numerous in traps set over shallow water where there was a dense plant growth though *Caenis horaria* was also common from deeper water where the bottom was almost bare mud. The Trichoptera occurred most frequently in traps set over vegetation in both shallow and deeper water.

3. Between different years there were differences of up to about six times in the size of the catches of insects belonging to different taxonomic groups. The total number of insects was greater at all sites in 1956 than in the other two years and this may have been due to the exceptionally warm and sunny July and August of 1955 which presumably favoured the survival of newly hatched larvae.

4. The total production at the water surface per annum was also measured by weighing the emerging insect fauna. The greatest weight produced was from shallow water with a dense growth of macrophytes though that from the deeper water with dense macrophytes was nearly as high. Deeper water with little vegetation produced the lowest weight of insects, less than one third that of the most productive site,

although the greatest numbers emerged from this site. The weights of some of the commoner species, which showed a range of over 350 times between the smallest and one of the largest species caught, are given.

5. The diurnal emergence rate of the total insect fauna is described from different sites for each month from April to September. Overall, the maximum emergence rate occurred in the late evening from June onwards with a peak also at midday in shallow water where there was a dense plant growth. There was no evening rise in emergence rate at the shallow water sites in May although this occurred in deeper water. At the only site where a sufficient number of insects emerged in late March and early April, all emergence occurred between 0800 and 1800 hrs. In all months the period 0400-0800 hrs was a time of low emergence activity, with the exception of one site in August.

6. The weight of insects produced during the peak periods showed that the greatest weight of insects emerging in two hours came from *Myriophyllum spicatum* growing in 6 ft of water in March-April when *Chironomus anthracinus* emerged. The greatest weight of insects emerging in two hours from May to August occurred from shallow weedy water, at midday, except in July when the greatest weight was caught from 2200-2400 hrs.

7. Seasonal variation in the numbers of insects emerging is described for different sites from 1955-1957. Emergence commenced in late March or early April and at all sites the main emergence took place between the beginning of April and beginning of September, a few insects emerging up to the end of October. In shallow water the maximum emergence occurred in late June and in early August at two different sites. At all four deeper water sites the maximum emergence rate was at the beginning of June, but the specific composition of the emergence maxima was different at each site. The emergence rate declined rapidly during late August at all sites. Emergence commenced in shallow water when the water temperature rose above 7·5°C and in deeper water when it rose above 6·0°C. Water temperatures are much higher than this at the end of the main emergence period and it is likely that the decline in emergence in late August is related either to the shortening length of day or to the natural depletion of all emerging species. The general pattern of emergence at the same site was similar from year to year, but there was considerable variation in the total number of insects emerging at a particular time of year, due to the variation in numbers and slight changes in the time of emergence of the more common species.

8. The seasonal variation in the total weight (biomass) of insects emerging was studied at three sites in 1957. At the shallow weedy site the seasonal fluctuations in weight were quite different from the fluctuations in numbers and this was related to the relatively high number of large insects, other than the small Chironomidae, which emerged here. There was a surprising weight increase in late September due to a few *Anabolia nervosa* which did not emerge at the other sites. At the deeper water sites with a higher proportion of Chironomidae the variation in weight corresponded more closely with the numbers emerging. The weight maxima occurred at different times at each site and the total weight of emerging insects declined rapidly in late August at all sites.

9. The number of species of Chironomidae emerging per week was directly proportional to the water temperature.

10. The significance of these results in relation to fish feeding studies is discussed and some suggestions are made for the improvement of fishing waters.

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